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ENVIRONMENTAL QUALITY, ENERGY, AND POWER TECHNOLOGY

Task Order 012: Plug-In Electric Vehicle, Vehicle-to-Grid

Jennifer Brendlinger, Matthew Campbell, James Hlivko, Heidi Kaltenhauser, Brian Wechtenhiser, and Greg Hafer

E2 Technologies LLC

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14. ABSTRACT *(Maximum 200 words)*
From 2015-2017, the DoD conducted a Plug-in Electric Vehicle – Vehicle to Grid (PEV-V2G) demonstration at four locations of non-tactical motor fleets – Los Angeles Air Force Base, Fort Hood, Joint Base Andrews and Joint Base McGuire-Dix-Lakehurst. V2G technologies provide financial and operational incentives to use PEVs beyond their primary function as vehicles. The concept of V2G is that a PEV is connected to the electrical grid via a bi-directional charging station. This allows the PEV battery to be marketed as an energy resource—receiving power from and providing power to the grid on a coordinated signal from the utility or the facility energy management system. The V2G team worked with original equipment manufacturers and contractors in developing multiple vehicles and charging stations to demonstrate the technology, determine effect on fleet missions, and assess return on investment. Data was tracked on all asset performance, and the program worked closely with the local utilities to execute the V2G process. The concept of V2G was proven, but many individual technologies remain at a low technology readiness level, with reliability and performance issues. Additionally, infrastructure/maintenance costs remain substantial. The demonstration selected the best performers to optimize V2G participation and revenue for the participating installations.

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Through their vision, leadership and guidance, the Plug-In Electric Vehicle, Vehicle-to-Grid Program was able to overcome many obstacles and achieve much success.

EXECUTIVE SUMMARY

In November 2017, the Department of Defense (DoD) completed the final phase of a multi-year Plug In Electric Vehicle-Vehicle to Grid (PEV-V2G) Program. PEV-V2G coupled bi-directional compatible electric fleet vehicles and charging stations at four DoD sites in the continental United States—Los Angeles Air Force Base (LAAFB), Fort Hood, Joint Base (JB) Andrews and JB McGuire-Dix-Lakehurst (MDL).

Vehicle-to-grid (V2G) technologies provide financial and operational incentives to use plug-in electric vehicles (PEVs) as an energy resource beyond their primary function as a mobility asset. A V2G-capable PEV is interconnected to the electric grid via a bi-directional charging station whenever it is not being driven. One of several services through which value can be derived from V2G is using the PEV battery to help stabilize the grid—receiving power from the grid (regulation down) and providing power to the grid (regulation up) on a coordinated signal from the utility or the facility energy management system.

The PEV-V2G program provides evidence of the DoD tradition of pushing technological boundaries to the betterment of the Armed Services and the nation. PEV-V2G involved multiple Service branches, pilot demonstration sites, vehicle and charging station equipment manufacturers, utility providers, regulatory authorities, and the utility regional transmission operators (RTOs)/independent system operators (ISOs).

The DoD has strategic, financial and mandated interests to reduce petroleum consumption and greenhouse gas (GHG) emissions. In response, military installations have been replacing their non-tactical vehicle fleet (powered primarily by gasoline) with hybrids, PEVs, and other vehicles fueled by alternative energy.

The PEV-V2G program had three major goals:

1. Demonstrate V2G technology can work
2. Evaluate how V2G supports or interferes with mission operations
3. Determine if/how PEVs can achieve cost parity with conventional vehicles, by collecting and analyzing data quantifying the impact of V2G implementation in differing environments and energy markets.

The Air Force Research Laboratory (AFRL) – Advanced Power Technology Office (APTO) assisted the Assistant Secretary of the Air Force for Installations, Environment and Energy (SAF/IE) and the Office of the Assistant Secretary of the Army for Installations, Energy and Environment with developing a unified DoD approach for deploying PEV-V2G applications.

A V2G system is technically complex to implement, as many technologies are not fully commercialized. Although the PEV-V2G program proved V2G works, it also demonstrated few of the components were fully mature. The system maturity and reliability of some V2G-capable PEVs, charging stations and V2G support equipment significantly improved throughout the PEV-V2G program. Those that did not improve were removed from the program in preparation for each individual location’s plans for sustainment of its PEV or V2G assets.

By the November 2017 conclusion of the technical activities under the Demonstration, the following achievements occurred:

- LAAFB conducted a fully automated V2G demonstration in two phases—1) with both regulation up (vehicle discharge) and regulation down (vehicle charge) market participation under control of a California Independent System Operator (CAISO) dispatch signal from December 18, 2015 through January 26, 2017 and 2) regulation up only from January 27, 2017 through September 30, 2017. The Fleet Management System (FMS), used to create vehicle reservations and schedule vehicles for trips, was fully integrated into the base's standard operating procedures. This allowed both the fleet manager and the PEV-V2G control software to maintain cognizance of the charge state of each PEV battery, as well as the range capabilities of each PEV at all times to dispatch vehicles properly. The PEV-V2G control software used its understanding of base mission requirements, vehicle availability, battery capacity and state-of-charge (SOC), historical day-ahead pricing and ancillary services market requirements to automatically create and submit day-ahead bids for the CAISO market and satisfy CAISO awards.

- JB Andrews conducted a semi-automated V2G demonstration, with both regulation up (vehicle discharge) and regulation down (vehicle charge) market participation under control of a PJM dispatch signal. The base elected not to utilize the FMS, instead committing the vehicles for use from 4 p.m. to 7 a.m. on weekdays and all day on weekends. Manual processes were employed very successfully to assess vehicle availability and submit day-ahead market participation bids.

- Fort Hood installed and implemented all needed V2G infrastructure, equipment and software and successfully conducted simulated market testing, while refraining from actual market participation due to current ancillary services market challenges. Viridity Energy conducted the simulation, meeting Army goals by proving system performance and enabling future options. Should Fort Hood decide to enter the market, Viridity indicated it "would have no reservations representing this system in the Electric Reliability Council of Texas (ERCOT) Regulation Up and Regulation Down markets."

- JB MDL did not conduct a V2G demonstration, as no V2G-capable PEVs were delivered due to production issues.

The PEV-V2G program incorporated three regional energy organizations and multiple ancillary services markets. LAAFB achieved commercial operation in the CAISO market on December 18, 2015 and participated until September 30, 2017. JB Andrews began market participation in the PJM market on April 21, 2017 and continues to participate as of the writing of this report. From July 29, 2016 through August 5, 2016, Fort Hood simulated participation in the ERCOT market and gained an understanding of qualification, participation and performance criteria. All factors considered, the PJM market was the most favorable for a research, development, test and evaluation (RDT&E) pilot program.

- PJM qualification capacity (total battery capacity necessary to participate in the market) is substantially less than CAISO.

- The PJM minimum accuracy requirements (allowed failures in response to market demand) are more lenient than CAISO.

- Monthly revenue was significantly higher for JB Andrews (PJM) than LAAFB (CAISO), even though the fleet size at LAAFB was much larger.

The PEV-V2G program demonstrated that V2G technology supports DoD non-tactical fleet operations and generates revenue from V2G market participation. However, cost parity with conventional vehicles can only be achieved after V2G equipment is fully commercialized, leading to improvements in system reliability. The demonstration helped advance bi-directional technologies and established valuable infrastructure for sustaining and developing further electric vehicle activities in future years.

1.0 INTRODUCTION

The Department of Defense (DoD) has strategic, financial and mandated interests to reduce its petroleum consumption and greenhouse gas (GHG) emissions. Recent mandates, such as the Energy Policy Act of 2005, the Energy Independence and Security Act of 2007 (EISA), and Executive Orders 13423 and 13514, all emphasize the need for the DoD and its Services to reduce fossil fuel and energy consumption while increasing use of alternative fuels and alternative fuel vehicles (AFVs).

The advent of vehicle-to-grid (V2G) technologies provides financial and operational incentives to utilize plug-in electric vehicles (PEVs) as an energy resource beyond their primary function as a mobility asset. A V2G-capable PEV is interconnected to the grid via a bi-directional charging station when it is not being driven. One of several services through which value can be derived from V2G is using the PEV battery to help stabilize the grid—receiving power from the grid (regulation down) and providing power to the grid (regulation up) on a coordinated signal from the utility or the facility energy management system.

From the DoD (installation) perspective, V2G systems offer an opportunity to earn money when vehicles are not being driven. In addition to payment for V2G services, PEVs with V2G capability may be used to support energy surety on installations (not demonstrated in this program). From an energy provider's perspective, V2G systems offer another means to match electrical demand with power availability. This technology expands vehicle usefulness beyond transportation, allows for a price stable fuel source, and enables revenue generation by participation in the ancillary services market.

1.1 Objective and Goals

The primary objective of the PEV-V2G program was to implement V2G technologies and conduct PEV-V2G demonstrations at four pilot sites—Los Angeles Air Force Base (LAAFB), Fort Hood, Joint Base (JB) Andrews and JB McGuire-Dix-Lakehurst (MDL).

The PEV-V2G program had three major goals:

1. Demonstrate V2G technology works
2. Evaluate how V2G supports or interferes with mission operations
3. Determine if/how PEVs can achieve cost parity with conventional vehicles, by collecting and analyzing data quantifying the impact of V2G implementation in differing environments and energy markets.

This Final Report describes the implementation, operating environment, testing performed, operational data acquired, and general results of this program. Lessons learned are summarized for optimal benefit in future efforts. In addition, a summary is provided of the cost-benefit analysis (CBA) used to evaluate PEV-V2G program results and determine the path forward.

1.2 Background

The majority of the United States (U.S.) electric grid is a complex but relatively reliable system. However, it does not inherently have energy storage capacity, resulting in simultaneous energy generation and consumption. This creates demand for a market whereby grid operators can allow third parties to sell energy generation or consumption on an as-needed basis, also known as the ancillary services market. PEV batteries can be utilized when a vehicle is connected to a charging station through bi-directional power interfaces, thereby allowing stored battery power to flow back and forth between vehicle and the grid to satisfy demand.

The primary markets for ancillary services include:

1. Reserve capacity to provide electricity if the grid has an unexpected need for more power on short notice
2. Frequency regulation services correcting for short-term changes in electricity generation or consumption, affecting the stability of the power system
3. Demand response services to quickly reduce system loading, ensuring secure operations of the transmission grid
4. Load acting as resource (LaaR) services offering a means for customers to increase their electric demand in response to instructions from the grid operator.

The PEV-V2G program was primarily concerned with the second of these, frequency regulation services. Grid frequency must be maintained at or near the nation's nominal 60-hertz (Hz) standard. To accomplish this, grid operators have the continuous task of matching grid electrical demand and power generation. This continuous adjustment of grid power flow to maintain system frequency is referred to as "frequency regulation."

In geographic areas where frequency regulation markets exist, frequency regulation is implemented by real-time communication from the grid operator to generation and load resources with a regulation control to adjust system frequency either up or down. Battery energy storage systems and fast-reacting power conditioning equipment are well postured to meet this need with limited fuel requirements. This ancillary service market helps ensure grid stability and supports reliable operation of the transmission system as electricity moves from generating sources to retail customers.

PEVs, through the on-board energy storage in their batteries, can instantaneously provide these regulating functions if connected to the grid through bi-directional power interfaces and equipped with appropriate communications. By controlling their charging profile, vehicle batteries can be commanded to release their stored energy to the grid as a generation source or commanded to become an energy consumer through recharging.

In 2011, the DoD launched the PEV-V2G program as part of its overall PEV Program. The DoD PEV Program supported the nation's goals of reducing dependence on foreign oil and becoming more energy efficient. The Office of the Secretary of Defense (OSD) assigned the Assistant Secretary of the Air Force for Installations, Environment and Energy (SAF/IE) to be the executive agent of the PEV Program. Significant direction and support was also provided from the Office of the Assistant Secretary of the Army for Installations, Energy and Environment. The program included Air Force, Army and Joint Base pilot demonstration sites, vehicle and charging station original equipment manufacturers (OEMs), utility providers, regulatory authorities, and the utility regional transmission operators (RTOs)/independent system operators (ISOs).

V2G-capable assets consisted of bi-directional electric vehicles supply equipment (EVSE), also known as “charging stations,” and PEVs or plug-in electric hybrid vehicles (PHEVs), many of which were custom designed and modified to support V2G activities. In addition, software was developed to manage the vehicle fleets and enable bidding into the ancillary services energy market.

1.2.1 Pilot Locations

Because operational impact and economic feasibility results may be installation and/or region specific, four pilot sites with differing characteristics were selected to help represent critical decision factors. These factors included service type, electrical grid territory, base size, climate and vehicle requirements.

The four sites were:

1. Los Angeles Air Force Base (LAAFB), California
2. Joint Base (JB) Andrews, Maryland
3. Fort Hood, Texas
4. JB McGuire-Dix-Lakehurst (MDL), New Jersey.

The selected sites encompassed three regional energy organizations: California Independent System Operator (CAISO) in the West; PJM Interconnection LLC (PJM), a RTO in the East; and Electric Reliability Council of Texas (ERCOT), an ISO in the Southwest.

1.2.1.1 LAAFB

LAAFB is the headquarters for the Space and Missile Systems Center (SMC) and the 61st Air Base Group. The main installation is located in El Segundo, California, about two miles south of Los Angeles International Airport (LAX). Fort MacArthur is a separate part of LAAFB and located 20 miles south. LAAFB was selected because it has a small, diverse general-purpose fleet of approximately 40 vehicles ranging from cars to 2-ton trucks and a shuttle bus. It also is located in a frequency regulation market, managed by CAISO and served by local provider Southern California Edison (SCE). Because LAAFB was slated to serve as a model for bringing PEVs into the United States Air Force (USAF) and DoD by replacing its entire non-tactical fleet with PEVs, it also was selected to be the first PEV-V2G pilot location.

1.2.1.2 JB Andrews

JB Andrews, located Maryland in the southeast outskirts of Washington DC. JB Andrews was selected for its east coast location and proximity to the nations’ capital and the Pentagon. In addition to providing a location with a colder winter climate, it is served by the PJM RTO. The local electrical utility provider is Pepco. The V2G plan for JB Andrews was to add a limited number of PEVs as an addition to the existing non-tactical fleet rather than attempting to fully replace the fleet with PEVs.

1.2.1.3 Fort Hood

Located in Killeen, Texas, Fort Hood is the largest armored post in the U.S. Armed Services. Situated between Austin and Waco in central Texas, Fort Hood covers 340 square miles. Fort Hood was selected as the Army's V2G partner location because it offered a different climate and geographic location, and it participates in a different market, managed by ERCOT. As with JB Andrews, the plan for Ft. Hood was to add a limited number of PEVs as an addition to the existing non-tactical fleet rather than attempting to fully replace the fleet with PEVs.

1.2.1.4 JB MDL

JB MDL is the nation's first tri-service joint base. Its name reflects the 2009 merger of McGuire AFB, Fort Dix, and Naval Air Engineering Station Lakehurst. Located 18 miles south of Trenton, New Jersey, and spanning more than 20 miles, JB MDL provided another east coast location, with potential for cold weather effects on the technology and the market. Like JB Andrews, JB MDL is served by the PJM RTO, but its local electrical utility provider is First Energy. The JB MDL plan was to add a limited number of PEVs as an addition to the existing non-tactical fleet rather than attempting to fully replace the fleet with PEVs.

1.2.2 Site Design & Construction

In each location, an isolated electrical system was established exclusively for the PEV-V2G project. This system began with a connection to a medium voltage electrical system and a large transformer to provide 480Y/277 volt (V) or 208Y/120 V secondary power to electrical distribution equipment. Parking lots were modified to provide a charging station mounting location for each parking spot. Both power and communications conduits were installed underground to each EVSE location. Physical equipment protection was necessary, so the design work incorporated the use of bollards or guard rails as appropriate.

1.2.3 Communications Infrastructure Design

Design of the network equipment infrastructure followed a basic model where a firewall/border router terminating the external Internet connection, to protect the server, charging stations and other network gear located behind the server. The V2G network was segregated from the installation network, and access controls were implemented on the firewall to limit users' connectivity to their respective areas of responsibility. Virtual local area networks (VLANs) were used to logically separate network traffic to specific areas of operation and responsibility. An intrusion detection system was implemented as part of the design to alert administrators of rogue and abnormal activity. All infrastructure equipment deployments used DoD-approved equipment with the equipment adhering to Defense Information Security Agency (DISA) Security Technical Implementation Guides (STIGs).

1.2.4 Vehicles

Five vehicle manufacturers were selected to participate in the original PEV-V2G demonstration. Table 1 provides basic facts about the selected vehicles.

Table 1. PEV-V2G Vehicle Specifications

Manufacturer	Nissan	Ford/EVAOS	VIA Motors	EVI	Phoenix
Model	LEAF	F-Series Trucks modified with EVAOS kits	VTRUX	REEV	Electric Shuttle
Description (Count)	4-door Sedan (13)	- F-150 Pickup (19) - F-250 Pickup with Crew Cab (11) - F-350 Pickup (2)	- Cargo Van (1) - 12-Passenger Van (8)	- Stake Bed Truck (2) - Box Truck (2)	Bus (1)
Vehicle Type	PEV	PHEV	PHEV*	PHEV*	PEV
Electric Range	75 miles	N/A	31 miles	40 miles	100 miles
Fuel Efficiency	99 MPGe	45 MPG**	38 MPG**	43 MPG**	32 MPGe
Cargo Capacity (cu ft) / Payload (lbs)	23.6 cu ft	1,500 to 2,800 lbs	2,650 lbs (cargo van only)	5,300 lbs	116 cu ft
Seating	5 seats	- Standard Cab: 3 seats - Crew Cab: 6 seats	- Cargo Van: 2 seats - Passenger Van: 12 seats	2 seats	Visitor Transport: 12 passengers + driver
Battery Capacity	24 kWh	27 kWh	21 kWh	54 kWh	102 kWh

MPG = miles per gallon; MPGe = miles per gallon equivalent; lbs = pounds; cu ft = cubic feet; kWh = kilowatt-hours

* Fuel used only when electric range exceeded

** Averaged over 60 miles

Table 2 shows the number of vehicles planned for each demonstration site.

Table 2. PEV-V2G Vehicles per Demonstration Site

Manufacturer	Nissan	Ford/EVAOS*	VIA Motors	EVI	Phoenix
LAAFB	13 MY2012**	5 total: - 1 F-150 - 4 F-250	11 total:*** - 1 Cargo van - 8 12-passenger vans	4 total: - 2 Stake bed trucks - 2 Box trucks with covered beds	1
JB Andrews	8 MY2013	5 F-250	- - -	- - -	- - -
Fort Hood	8 MY2013	14 F-150	- - -	- - -	- - -
JB MDL	- - -	8 total: - 4 F-150 - 2 F-250 - 2 F-350	- - -	- - -	- - -

* Only 15 of planned 32 EVAOS were delivered.

** MY = Model Year

*** 9 vans were procured under the PEV-V2G program. The GSA supplied two additional VIA vans under a technology loan agreement with VIA that were also modified to be V2G, for a total of 11 V2G-capable VIA vans at LAAFB.

1.2.5 Charging Stations and V2G Support Equipment

V2G requires charging stations capable of transmitting energy not only to the vehicles but also into the electric grid on demand. EVSE selection is also highly dependent on vehicle selection where aligning the appropriate electrical connection including voltage characteristics is imperative. In addition, Tank and Automotive Research, Development, and Engineering Center (TARDEC), acting as the technical lead from the government project perspective, directed, where possible, the Society of Automotive Engineers (SAE) J1772 standards should be used for charging stations and interfaces to vehicles. This standard embraces both alternating current (AC) and direct current (DC) charging connections originating with the SAE. Nissan vehicles use CHAdeMO, a DC-connect charging standard originating in Japan. Unlike SAE system-wide standards, CHAdeMO does not address server communication standards, so Open Charge Point Protocol (OCPP) was used for communications between the LEAF EVSE and the V2G system server.

Note that AC and DC stations are distinguished by the charging connection to the vehicle battery. The electrical grid is based on AC power, while PEV batteries charge and discharge with DC power. An electrical inverter is required in the connection to change power between the AC and DC requirements. In what are termed "DC stations," the bi-directional inverter is located within the EVSE and the charge connection between EVSE and vehicle carries DC power. In what are termed "AC stations," the charge connection carries AC power to a bi-directional inverter located on the vehicle itself, where it is changed to DC before being used to charge the vehicle battery.

After determining SAE-compliant PEV/EVSE pairs were not available, an effort was executed to determine the best means to acquire this capability. The selected concept involved developing communications interface modules for both the EVSE and PEV from a single vendor. It was theorized this approach would significantly lower implementation risk by placing the most challenging interfaces with one vendor, while enabling simpler CANbus interfaces to the EVSE and PEV controls. Coritech Services was subsequently selected to provide all of the SAE-compliant EVSE (AC- and DC-connect) with these communications interfaces, which were named the Vehicle Interface Module (VIM) and EVSE Interface Module (EIM).

The VIM and EIM were novel V2G technologies. The VIM resided within the PEV and interacted with the PEV control through CANbus. It communicated to the EIM by Home Plug Green PHY (HPGP), a form of power line carrier communications imposed on the Control Pilot lead of the J1772 EVSE to PEV cable per SAE standard J2931-4. The EIM resided in the EVSE and communicated to the VIM via HPGP. The EIM communicated to the EVSE Control through CANbus. The EIM communicated to the V2G software via Smart Energy Profile 2.0 (SEP2) over Ethernet transmission control protocol/Internet protocol (TCP/IP).

A V2G-capable EVSE must be compatible with its paired vehicle. The vehicle's specifications dictated EVSE specifications related to AC or DC, type of interface (CHAdeMO or SAE), and power. The EVSE acquisition decision for each site was driven by the type of vehicles selected for each site.

Table 3 provides a brief summary of the PEVs and matching EVSE units implemented at each of the four demonstration sites. The EVSE capacity column has been derated to match realistic battery, inverter and power distribution limitations.

Table 3. Summary of Program Vehicles and Charging Stations

Vehicles	Vehicle Type	EVSE OEM	EVSE Capacity/ Type	Qty	Vehicle to EVSE Communication	EVSE to Software Communication
LAAFB				**34**		
Nissan LEAF sedan (5 passenger)	PEV	PPS	15 kW DC	13	CHAdeMO	OCPP
F-150 Ford Pickup Truck with EVAOS ESM	PHEV	Coritech	18 kW AC	1	SAE HPGP	SAE SEP2
F-250 Ford Pickup Truck with EVAOS ESM	PHEV	Coritech	18 kW DC	4	SAE HPGP	SAE SEP2
VIA vans (12 passenger)	PHEV	Coritech	14 kW DC	10	SAE HPGP	SAE SEP2
VIA van (cargo)	PHEV	Coritech	14 kW DC	1	SAE HPGP	SAE SEP2
EVI Stake Bed Truck	PHEV	Coritech	50 kW DC	2	SAE HPGP	SAE SEP2
EVI Box Delivery Vehicle	PHEV	Coritech	50 kW DC	2	SAE HPGP	SAE SEP2
Phoenix Bus (12 passenger + driver)	PEV	Coritech	50 kW DC	1	SAE HPGP	SAE SEP2
JB Andrews				**13**		
Nissan LEAF sedan	PEV	PPS	30 kW DC	8	CHAdeMO	OCPP
F-150 Ford Pickup Truck with EVAOS ESM	PHEV	Coritech	18 kW DC	5	SAE HPGP	SAE SEP2
Fort Hood				**22**		
Nissan LEAF sedan	PEV	PPS	15 kW DC	8	CHAdeMO	OCPP
F-150 Ford Pickup Truck with EVAOS ESM	PHEV	Coritech	18 kW DC	14	SAE HPGP	SAE SEP2
JB MDL				**8**		
F-150 Ford Pickup Truck with EVAOS ESM	PHEV	Coritech	18 kW DC	4	SAE HPGP	SAE SEP2
F-250 Ford Pickup Truck with EVAOS ESM	PHEV	Coritech	18 kW DC	2	SAE HPGP	SAE SEP2
F-350 Ford Pickup Truck with EVAOS ESM	PHEV	Coritech	18 kW DC	2	SAE HPGP	SAE SEP2

Qty = quantity; ESM = Energy Storage Module; kW = kilowatt

1.2.6 Software

The transition from conventional vehicles to a PEV fleet required a fundamental change in fleet management strategies. Primarily, the fleet manager needed to maintain cognizance of the charge state of each PEV battery, as well as the range capabilities of each PEV at all times to dispatch vehicles properly. Integrating V2G activities into a PEV fleet creates additional layers of complexity. In a V2G model, the PEV is treated as an energy asset in addition to its traditional role as a mobility asset. Information regarding the PEV charge state and range capabilities must be integrated with energy data from the facility and public electrical grid to optimize the PEV's energy functions without diminishing its primary mobility requirements.

LBNL and its subcontractor, Kisensum, designed and developed the On-Base Electric Vehicle Infrastructure (OB-EVI) software architecture to perform the activities required for participation in CAISO's ancillary services market. OB-EVI included four key modules—the Fleet Management System (FMS), the Charge Control Module (CCM), the Grid Scheduling Module (GSM) and the ISO Interface Module (IIM):

- The FMS was designed to support military base transportation scheduling by providing an automated solution for dispatch personnel to administer reservations and input requests to drive EVs and/or PEVs on or off the base. The FMS created schedules that were used to optimize the use of the EV batteries when the cars were not in use and collected driving/usage behavior and patterns to further optimize EV usage. It used the current battery state to determine whether an EV about to be picked up by base personnel had a sufficient state-of-charge (SOC) to safely make the scheduled trip. This system included a web interface that could be used by dispatchers and Unit Vehicle Control Officers to schedule and manage the dispatching of cars.
- The CCM had responsibility for managing the charging and discharging of individual vehicles. This module accepted commands to charge the vehicles to prepare for specific trips and to determine how to meet the ISO charge or discharge requirement. This logic utilized the University of California, Berkeley (UC Berkeley) developed Real-Time Charging Controller (RTCC), which disaggregated the regulation signal from the ISO into individual vehicle charge and discharge commands while attempting to maintain the optimal energy storage levels predefined by the optimized GSM charge plan. This module also tracked vehicle interconnection and the actual state of charge for each vehicle.
- The GSM contained all of the logic needed to optimize the grid resource (batteries) availability and prepare for the scheduling coordinator or QSE to submit to the ISO. This module performed the following functions: 1) developed forecasts and short-time horizon reoptimization, 2) established operating limits based on EV schedules established by the FMS module, and 3) determined when vehicles would be parked and available for inclusion in the resource bid into the ISO markets.
- The IIM was a software interface layer that implemented the unique interfaces necessary to communicate with the ISO and the scheduling coordinator or QSE for a given implementation. This module also implemented the unique requirements of each scheduling coordinator or QSE to submit the day-ahead ancillary services bids to the ISO.

This module isolated all of the unique aspects of communicating with the off-base components and converted them to an implementation-specific standard internal format. This module communicated with the external ISO interfaces, as well as email and other interfaces to the QSE to place bids.

1.2.7 Certification and Accreditation (C&A)

The DoD requires that, for a system to operate on a military base network, one of the following accreditation decisions must be obtained:

- IATT – Interim Authority To Test (inside given timeline only).
- IATO – Interim Authority to Operate (provisions set forth in Plan of Action and Milestones required).
- ATO – Authority to Operate (no provisions required).

In addition, for a system to access an outside network or use an Internet Service Provider, a Global Information Grid (GIG) waiver must be obtained. Certification and Accreditation (C&A) activities occurred at all pilot locations to allow operations, with the goal of achieving an accreditation decision of at least an IATT with a GIG waiver for actual market participation sites.

1.2.8 On-Board Data Collection Devices (OBDCs)

PEV-V2G included FleetCarma vehicular on-board data collectors (OBDC) for V2G vehicles participating in the ancillary services market, along with the installation of supporting data transfer and data archival infrastructure to facilitate retrieval of collected vehicle performance data. Vehicle performance data included battery state-of-charge, battery voltage, battery current, battery temperature, ambient temperature, fuel usage, average daily distance, total distance, idle time, vehicle speed and energy usage. This data was used to demonstrate and quantify the performance capabilities of PEV-V2G vehicles to support driving missions and participate in utility ancillary services markets, primarily in development of the enhanced CBA. Each OBDC, also known as a data logger, serviced one vehicle and collected the required vehicle performance data elements during vehicle driving and charging activities.

1.2.9 Transition Support and Property Restoration

At the conclusion of the V2G demonstration, the infrastructure was transitioned to meet the needs at each site. Sites not choosing to continue with V2G activities were able to use the infrastructure for uni-directional vehicle charging. The team developed a Transition Support Plan (TSP) for both Army and Air Force Installations that included instructions for all vehicles and charging stations.

2.0 PILOT AND DEMONSTRATION RESULTS

This section discusses the results of the demonstration at each pilot site. Participation in the frequency regulation market is detailed for each site, followed by an extensive breakdown of how the performance and reliability of each program component contributed to the end result.

2.1 LAAFB

LAAFB was determined by the Executive Agent to be the first installation to participate with frequency regulation in the local grid market. A sizeable, active electric motor fleet, supportive local Air Force management, and a utility supplier and ISO with a frequency regulation program and policies mature enough to support V2G operations all contributed to the LAAFB timeline entry into the market. The LAAFB electric vehicle parking lot and full PEV fleet is shown in Figure 1.

Figure 1. LAAFB Parking Lot and Full PEV Fleet

2.1.1 Utility/Regulatory

CAISO is an independent, non-profit ISO serving California. It oversees the operation of California's bulk electric power system, transmission lines, and electricity market generated and transmitted by its member utilities. The PEV-V2G program participated in two types of ancillary services products offered by CAISO—regulation up and regulation down.

Units and system resources providing regulation are certified by CAISO and must respond to automatic generation control (AGC) signals to increase or decrease their operating levels depending upon the service being provided, regulation up (discharging vehicle batteries to the grid) or regulation down (charging vehicle batteries from the grid). The PEV-V2G program participated in CAISO's day-ahead (DA) ancillary services market, which paid successful bidders the DA market clearing price (MCP) or the highest accepted bid for the award period.

To participate in the CAISO market, only a certified scheduling coordinator (SC) can directly bid resources, as well as handle the settlement process. Southern California Edison (SCE) was retained as the SC for LAAFB.

SCE is also the primary electric utility for LAAFB. Within SCE territory, distribution interconnections, generally below 66 kilovolts, are governed by SCE's Wholesale Distribution Access Tariff (WDAT). The WDAT provides the terms and conditions for service utilizing the distribution facilities under SCE's operational control. SCE administers its tariff, which is approved by the Federal Energy Regulatory Commission (FERC). New generation projects seeking interconnection to SCE's electric system are required to obtain "interconnection service."

In accordance with SCE requirements for allowing LAAFB to participate as a V2G pilot site, all V2G-capable PEVs and charging stations to be utilized at LAAFB were tested by SCE to confirm the safety, functionality and system impact of the charging systems. Testing conducted at SCE's EV Technical Center included the following:

1. Vehicle Baseline – This testing validated functionality, base performance results and the state of health of the vehicle.
2. Charger Baseline – This testing validated functionality and safety as well as determined base performance results of the charging station.
3. Bi-directional Anti-Islanding Test – This test determined if the system properly and safely disconnected from the grid when specific grid disturbances occurred.

SCE testing of all vehicles and paired EVSE at LAAFB was completed in April 2016.

2.1.2 Market Participation

As mentioned above, the PEV-V2G program at LAAFB participated in two CAISO frequency regulation ancillary services markets—regulation up and regulation down. Under this program, PEV battery capacity was sold to CAISO, allowing the vehicle batteries to be utilized as energy sources or sinks for the ancillary services market, with the resultant revenue offsetting utility bill costs.

Vehicle usage was managed with the FMS, the software application used to reserve and dispatch vehicles. The reservation provided information on the availability of the vehicles to allow the PEV-V2G control software to estimate the available battery capacity of the vehicles connected to the charging stations. This information was used to prepare a day-ahead bid for CAISO that defined available battery capacity in 1-hour increments for a 24-hour day.

When a bid was accepted (known as an award), CAISO provided a real-time demand signal identifying the specific amount of power and direction required. The system consumed the power to charge the batteries (regulation down, consuming excess supply) or used the batteries to provide power back to the grid (regulation up, making up for a supply shortfall). The PEV-V2G control software received the demand signal and provided commands to each individual charging station for a specific power setting to achieve the aggregate power requested by CAISO.

The following sections discuss: 1) the timeline for entering the CAISO ancillary services market and key milestones relative to market participation, 2) overall and available vehicle capacities, which affected the program's level of participation, 3) metrics regarding awarded market participation hours and energy levels, and 4) the revenue generated during the demonstration.

2.1.2.1 Significant Milestones

LAAFB's participation in the CAISO frequency regulation ancillary services market had several milestones.

2015

- October 15, 2015 – Successful qualification testing occurred. The PEV-V2G team, with the assistance of site personnel, executed the required CAISO test of an average of >= 500 kW discharge for 30 minutes and >= 500 kW charge for 30 minutes.
- December 15, 2015 – The PEV-V2G team received the Permission to Operate (PTO) letter from SCE and submitted it to CAISO.
- December 18, 2015 – CAISO issued its Commercial Operation Date (COD). The COD is the first date that bids could be submitted, allowing all vehicles in the LAAFB PEV-V2G project to bid into the ancillary services market.
- December 24, 2015 – LAAFB's first bid awarded.

2016

- May 1, 2016 – All V2G vehicle-EVSE pairs on site and fully functional for market participation; data collection efforts began.

2017

- January 26, 2017 – The PEV-V2G team received a notice of decertification from CAISO, decertifying the program for the regulation down market. According to CAISO, the V2G fleet failed to accurately respond to the regulation down AGC signal a minimum of 25% of the time during July and August 2016. This meant LAAFB's V2G fleet was no longer permitted to participate in the regulation down market. Regulation up only bidding commenced.
- September 30, 2017 – SCE ended its pilot demonstration period in compliance with the California Public Utility Commission's Resolution E-4595; consequently, the PEV-V2G team ceased all market participation activities.

2.1.2.2 Participation Capacity

From May 1, 2016 through January 31, 2017, 13 LEAFs, 11 VIAs, four Electric Vehicles International (EVIs) and the Phoenix bus participated in the market, for a total capacity of 549 kW. As of February 1, 2017, the VIAs and EVIs were removed from participation, reducing the total to 235 kW. Table 4 shows individual vehicle capacities in these timeframes.

Table 4. PEV-V2G Vehicle Capacities at LAAFB

	May 1, 2016 - Jan 31, 2017			Feb 1, 2017 - Sep 30, 2017		
Vehicle Type	Quantity	kW per Vehicle	Total Capacity (kW)	Quantity	kW per vehicle	Total Capacity (kW)
Nissan LEAF	13	15	195	13	15	195
Phoenix Shuttle	1	40	40	1	40	40
EVI Trucks	4	40	160	0	40	0
VIA Vans	11	14	154	0	14	0
Total	29		549	14		235

Market participation is only possible when both a vehicle and its paired charging station are functional and communicating with the OB-EVI software. Figure 2 shows the actual capacity of the vehicle/EVSE pairs available for market participation each day since May 1, 2016. For comparison, this graph also shows the capacity required for qualification in the CAISO market (500 kW) and the minimum bid requirement in the CAISO market (100 kW).

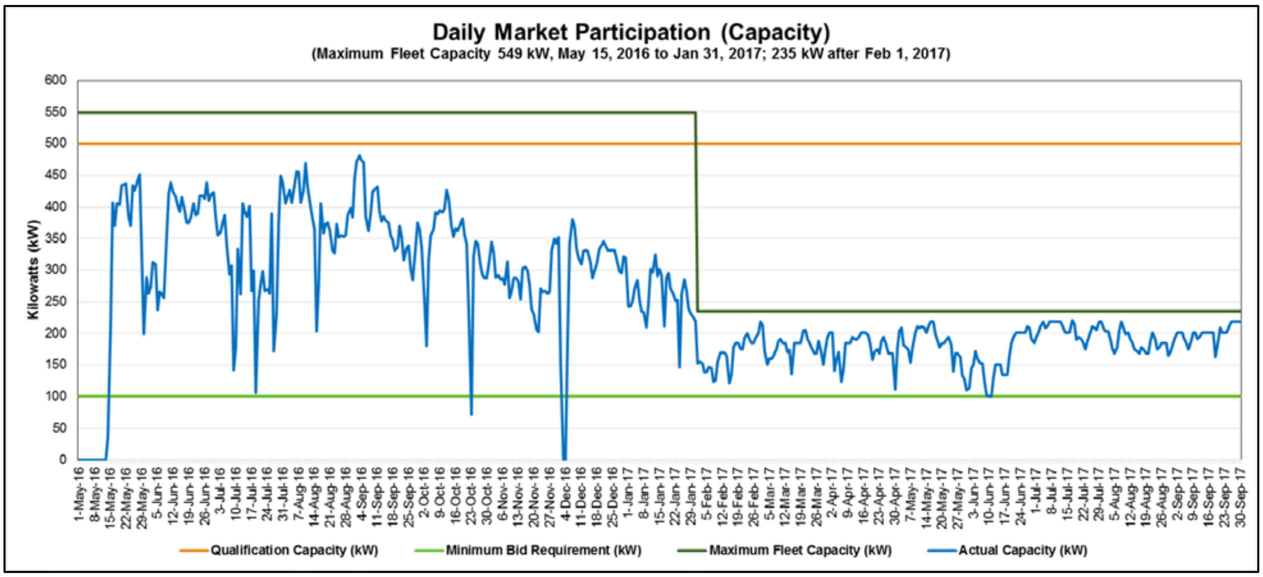


Figure 2. LAAFB Market Participation Capacity

2.1.2.3 Participation Metrics

Participation was based on operational status of the vehicle/charging station pairings and availability of the fleet outside of mission requirements.

Distribution Statement A. Approved for public release; distribution is unlimited.

- Bidding hours were initially restricted to 4 p.m. through 6 a.m. to ensure maximum availability for base missions during business hours. The hour from 6 a.m. to 7 a.m. was reserved for fully charging all vehicles in preparation for base missions.
- Bidding hours were further reduced to 4 p.m. through midnight due to cell balancing of EVI trucks and the Phoenix bus (conducted nightly after midnight) and battery health testing (conducted once per month per vehicle, after midnight on Saturdays). Cell balancing is a required maintenance activity that establishes uniform voltage of each cell within the battery pack in order to yield optimum pack performance.
- Bidding was increased when assets were available and operational.

Figure 3 shows the daily hours of participation according to CAISO's day-ahead awards for regulation up and regulation down, along with the goal of 13 hours on weekdays and 24 hours on weekends. This graph reflects the decertification of the pilot for Regulation Down as a zero award beginning January 26, 2017.

Figure 4 shows the daily total awarded energy levels for regulation up and regulation down through January 25, 2017, and regulation up only thereafter. Figure 4 also shows energy level goals decreased by the average time taken to perform cell balancing of the EVI trucks and Phoenix bus from May 1, 2016 through January 31, 2017, and the average time for just the Phoenix bus thereafter. This graph shows an overall .5 megawatt-hour reduction in market participation energy since May 1, 2016, demonstrating the effects of reduced capacity shown in Figure 2 and the decertification of the program for regulation down shown in Figure 3.

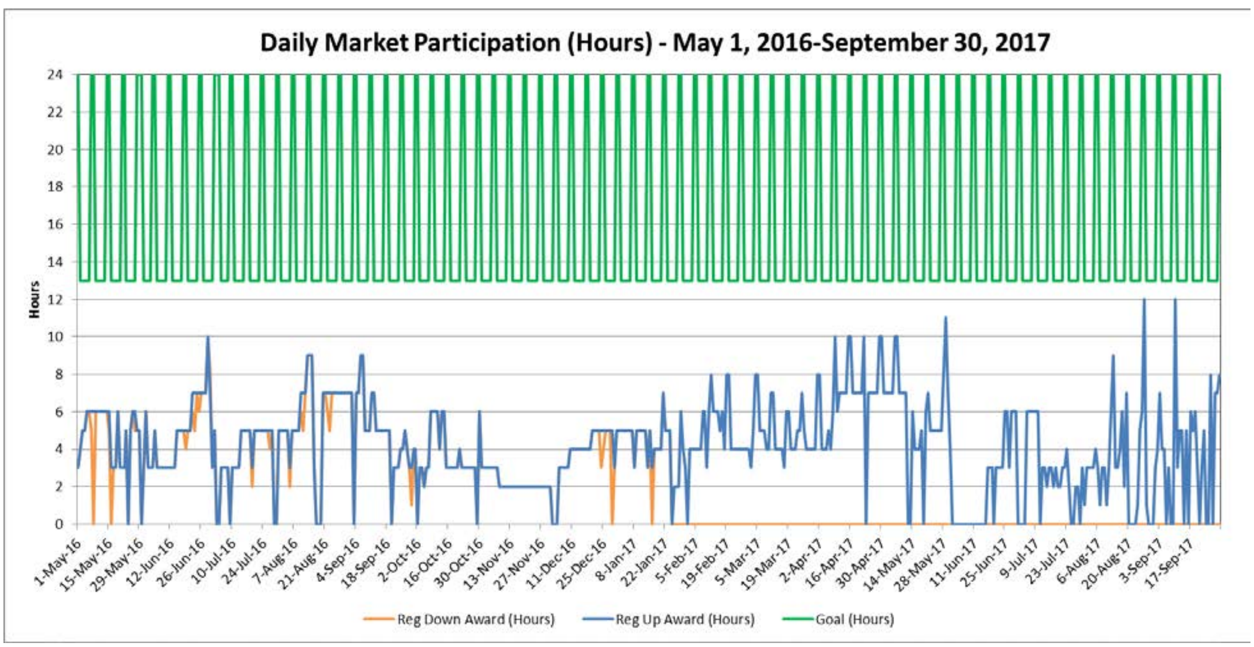


Figure 3. LAAFB Market Participation Hours

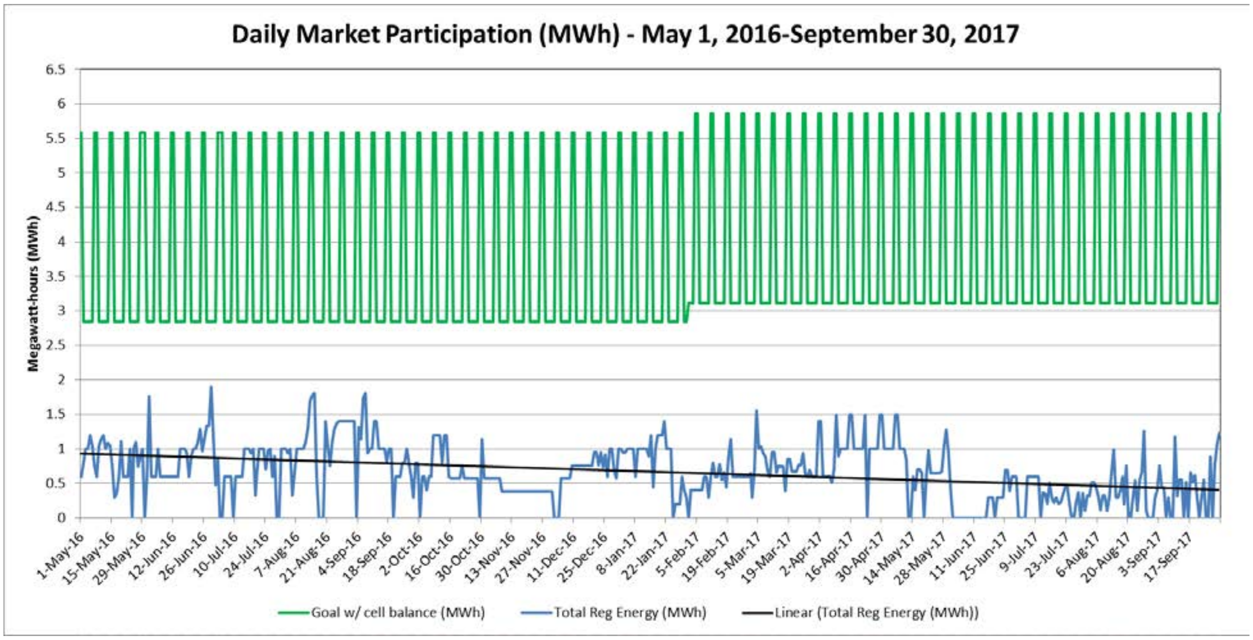


Figure 4. LAAFB Market Participation Energy

2.1.2.4 Participation Revenue

Market participation revenue for the LAAFB demonstration was dependent on many factors, including equipment availability, day-ahead pricing for the regulation up and regulation down markets, and CAISO's energy needs. Revenue from December 2015 through April 2017 totaled $7,639. Monthly fees assessed by SCE included a scheduling coordinator fee of $1,000, a manual billing fee of $118.46, and a meter data feed fee of $216.50. Revenue and fees appeared as adjustments on the base's monthly utility bill from SCE. Figure 5 shows LAAFB revenue through April 2017. Figure 6 and Figure 7 show historical pricing data from CAISO.

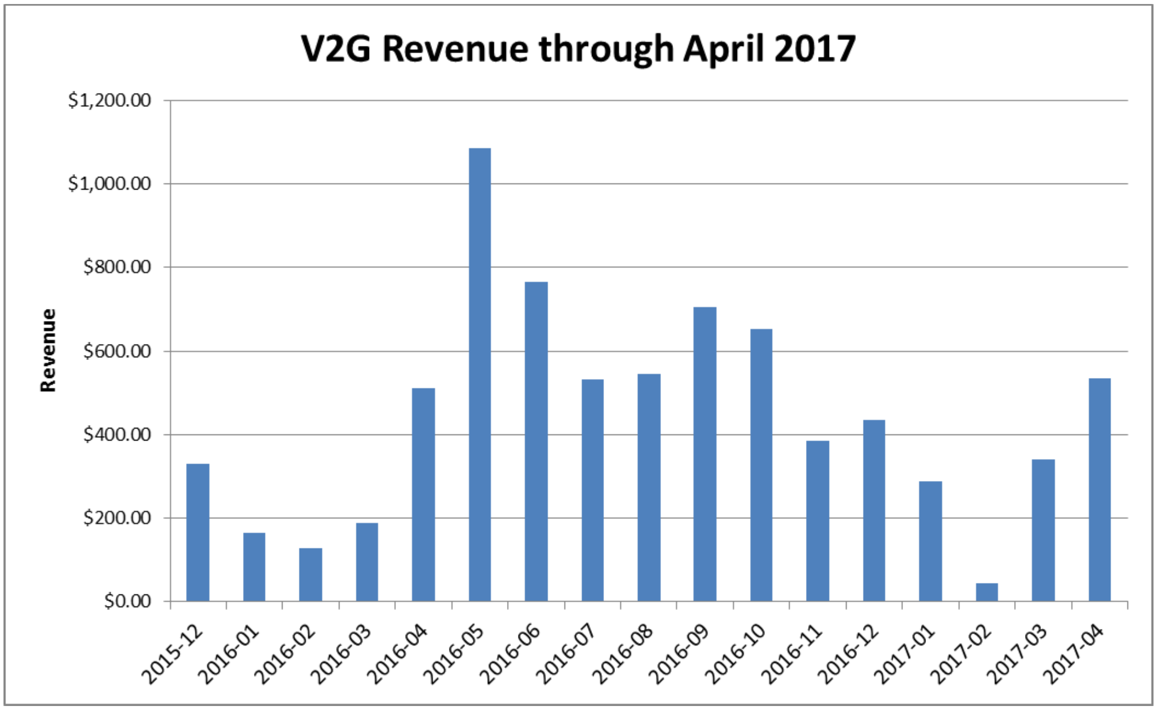


Figure 5. LAAFB Revenue

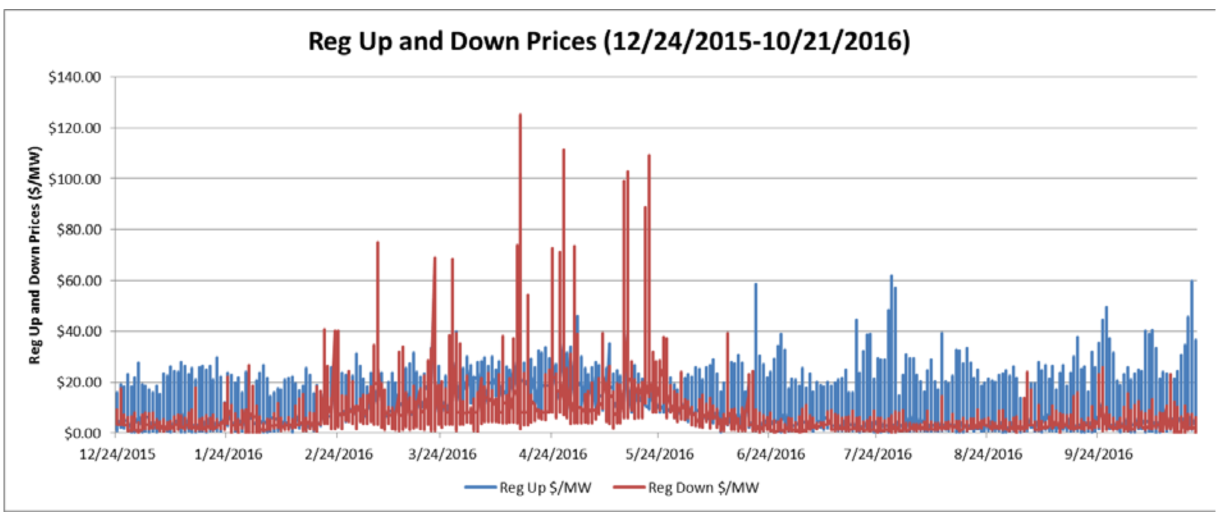


Figure 6. CAISO Pricing (December 24, 2015-October 21, 2016)

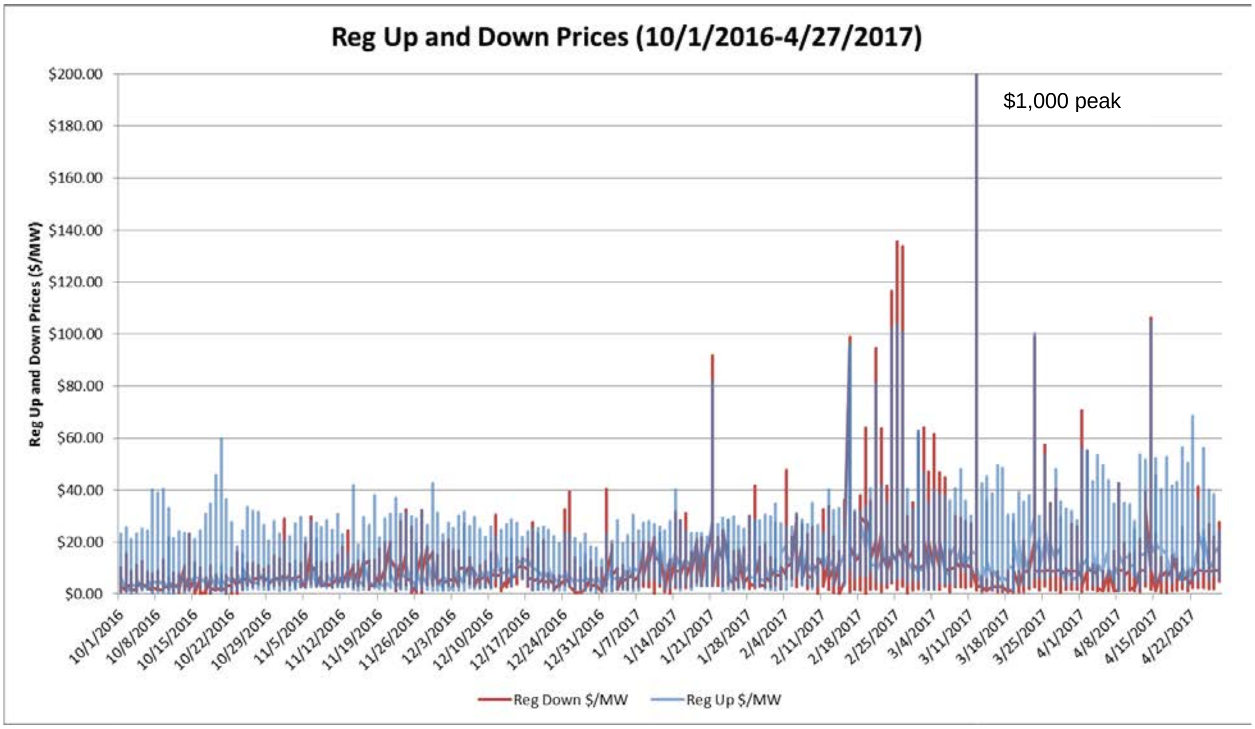


Figure 7. CAISO Pricing (October 1, 2016-April 27, 2017)

2.1.3 Vehicles

Five types of bi-directional PEVs were demonstrated at LAAFB. The manufacturers were EVI, Electric Vehicle Add-On Systems (EVAOS), Nissan, Phoenix Motorcars, and VIA Motors (VIA). PEV models and quantities are shown in Table 5, along with vehicle type (PEV or PHEV).

Table 5. PEV-V2G Vehicles at LAAFB

Manufacturer	Model	Vehicle Quantity	Vehicle Description
EVI	REEV	4	2 Stake bed truck and 2 box trucks; PHEV
EVAOS	Ford F-series	5	5 total:1 F-150, 4 F-250
Nissan	LEAF	13	Model Year 2012 Sedans; PEV
Phoenix Motorcars	Phoenix Shuttle	1	Passenger shuttle; PEV
VIA Motors	VTRUX	11	Vans: 1 Cargo van, 8 12-passenger vans; PHEV

Additionally, eight non-V2G PEVs were operated at LAAFB—four Ford C-Max, two Chevrolet Volts, and two non-V2G VIA vans. The status and performance of each V2G vehicle type during the demonstration is discussed in the following sections, with a focus on impacts to driving missions and V2G demonstration.

2.1.3.1 Nissan LEAFs

Nissan LEAFs are a four-door, five-passenger standard model PEV sedan offered by Nissan. They have a driving range of up to 75 miles. When creating LAAFB's electric vehicle fleet, LEAFs were utilized to replace as many internal combustion engine (ICE) vehicles as possible. However, many of LAAFB's driving missions required either a much large passenger capacity or a cargo transport capacity, and other vehicle types were brought into the demonstration to meet those needs. No work was required in order to make the model year 2012 Nissan LEAFs capable of V2G operations. Bi-directional power transfer capability is standard on 2013 and later model year LEAFs, and Nissan North America provided a software patch that enabled bi-directional charging on the 2012 model years. Figure 8 shows a Nissan LEAF sedan at LAAFB.

Figure 8. Nissan LEAF Sedan at LAAFB

LEAFs were driven regularly at LAAFB through the demonstration period. Due to the limited electric range of the vehicles, operator preference was to utilize them for short day trips to a specific location, spending most of the day parked at that location. The thirteen Nissan LEAFs remained as part of LAAFB's vehicle fleet at the conclusion of the demonstration.

2.1.3.2 VIA Vans

VIA VTRUX model vans are rebuilt from a Chevrolet Express 2500 van into a PHEV capable of operating in fully electric mode, only utilizing the ICE when the vehicle battery is exhausted. Rather than directly moving the driveshaft, the ICE can act as a generator to continuously recharge the van while it is being driven. At the time of procurement, VTRUX vans were still limited to a low initial production run, with VIA having produced only hundreds of vans for initial sale. These were in many ways still prototype units, with VIA committed to refining and improving the design in future model years. Despite the relative immaturity of the technology, VIA was the best candidate for a hybrid electric van that would be able to meet LAAFB's range requirements of over 100 miles without a recharge. Figure 9 shows one of the VIA vans at LAAFB.

Figure 9. VIA Van at LAAFB

The base VIA VTRUX van model utilized an onboard uni-directional inverter to charge the vehicle. VIA designed and installed a bi-directional inverter capable of supporting V2G activity on eleven vans specifically procured for this effort. Ten vans were in the passenger configuration, able to seat passengers in the rear. The remaining van was in the cargo configuration, with its rear space cleared for cargo transport

Some of the vans were unavailable for periods of weeks or months due to technical issues. Despite this, the passenger vans saw extensive mileage due to their placement on a regular mass transit route in which the vans were continually driven on a circular route around the base, picking up and dropping off personnel. While on this mission, vans could be driven almost 100 miles, or up to 13 transit loops, during the course of a day. Note that the vans were typically not recharged mid-mission, meaning that the vans would transition to running on their ICEs after exceeding their electric-only range. The cargo vans and passenger vans were also used in a variety of day trip applications.

In June 2017, the United States Marine Corps (USMC) took possession of the nine DoD-owned vans to use in further electric vehicle projects. VIA Motors reclaimed the two vans that were on loan for the demonstration.

2.1.3.3 EVI Trucks

Four PHEV trucks were procured from Electric Vehicles International LLC. These were prototypes of EVI's Range Extended Electric Vehicle (REEV) model. REEV trucks were built on a Ford F-550 chassis using EVI's custom drive system. They were PHEVs capable of operating in a fully electric mode, only utilizing the ICE when the vehicle battery was discharged. Two REEVS were stake bed trucks with lift gates, which provided capacity to haul local cargo loaded by dolly, forklift or from a dock. The other two were box trucks, which provided base personnel with medium-sized enclosed cargo movement capabilities. Figure 10 shows an EVI REEV truck at LAAFB.

Figure 10. EVI REEV at LAAFB

REEV trucks were prototypes, with less than ten in existence at the time the V2G demonstration vehicles were constructed. With the lack of maturity of the technology, there were very few options for heavy-duty PHEV trucks with a multi-ton load capacity at the time vehicle procurement was initiated. During the selection process, REEVs were the best available design to meet LAAFB performance requirements. The base REEV was not designed for bi-directional charging, so EVI undertook a separate engineering project to make the four LAAFB trucks V2G capable and integrate the Coritech VIM. EVI was purchased by First Priority GreenFleet, ending plans for further production or development of the REEV trucks under the demonstration.

REEV trucks were mostly used for short distance travel on base. As there were few on-base missions requiring transport of heavy cargo, the REEVs had fewer driving missions and accrued relatively little mileage over the course of the demonstration. In June 2017, the four REEVs were transferred to USMC for use in further electric vehicle projects.

2.1.3.4 Phoenix Bus

One 12-passenger Phoenix shuttle bus was procured from Phoenix Motorcars for use during the demonstration. The shuttle was an early production prototype vehicle built using an El Dorado Aerotech chassis, built on the Ford E350 cutaway cab. The mission requirement for this vehicle at LAAFB was to have a suitable transport for visiting dignitaries from arrival at the airport to LAAFB. In order to accommodate this mission, the Phoenix shuttle was outfitted with accessories such as power outlets and overhead luggage racks.

The Phoenix Shuttle was an all-electric prototype suitable for public roads but primarily intended for low-speed transport. The Phoenix was one of very few options for an EV transport capable of carrying 10+ people and outfitted with the required accessories. The base Phoenix technology was not designed for bi-directional charging, so Phoenix Motorcars undertook a separate engineering project to make the shuttle V2G capable and integrate the Coritech VIM. Figure 11 shows the Phoenix Shuttle at LAAFB.

Figure 11. Phoenix Shuttle at LAAFB

The shuttle was regularly used on a mass transit route in which it was continually driven on a circular route around the base, picking up and dropping off personnel. While on this mission, the shuttle typically ran 40 to 50 miles, or approximately six transit loops, per day. As a secondary application, the shuttle was used to transport dignitaries to and from the airport on an approximately monthly basis. Regular usage on the transit loops caused a high driving mileage over the course of the demonstration.

The Phoenix Shuttle remained as part of LAAFB's vehicle fleet at the conclusion of the demonstration.

2.1.3.5 EVAOS Trucks

Five F-series Ford pick-up trucks were leased from General Services Administration (GSA) by LAAFB for this V2G effort. These trucks were modified by EVAOS to be PHEV as shown in Figure 12.

Figure 12. EVAOS-Equipped F-150 Truck

EVAOS provided and installed an aftermarket modification to convert an existing internal combustion vehicle into a PHEV with increased fuel efficiency and range. EVAOS kits can be installed in either the Ford F-150 (light-duty pickup truck) or the Ford F-250 or F-350 (¾- to 1-ton pickup trucks). At the time of procurement, EVAOS technology was a prototype design for the demonstration, with EVAOS committed to refining and improving the design for future customers.

Many light and medium duty pick-up trucks are in service for the non-tactical vehicle fleets of many military bases due to their ability to combine light cargo movement with personnel transport. Even with the relative immaturity of the EVAOS technology, it was the best candidate for a PHEV technology that could be utilized with pick-up trucks already available for lease from GSA.

Due to technical issues, the EVAOS-modified trucks were used for a limited number of driving missions before being taken out of service.

2.1.4 Charging Stations

Managed power flow between vehicles and the grid requires coordination of many technologies whose collective purpose is to provide end-to-end control and monitoring of this activity. Performance of the charging stations and V2G support equipment played a large role in this control and monitoring.

2.1.4.1 Princeton Power Systems (PPS) EVSE

Figure 13 shows a PPS CHAdeMO-compliant DC EVSE installed at LAAFB. The basic PPS bi-directional inverter is rated at 30 kW, but was limited to 15 kW for operation with the LEAFs at

LAAFB. These charging stations connect to the vehicles through a CHAdeMO connector. Thirteen PPS DC bi-directional EVSE were installed and commissioned for use with the Nissan LEAF vehicles for the demonstration. The PPS EVSE remained in use at the conclusion of the program.

2.1.4.2 Coritech AC EVSE

Figure 14 shows a Coritech SAE-compliant AC EVSE installed at LAAFB. Per SAE J1772 standards, the connection to the vehicles is limited to 240 volts alternating current (VAC) single phase at up to 80 amps (19.2 kW maximum). However, in uses such as LAAFB, where the stations are fed by 208 VAC single phase, the actual power limit is 16.6 kW.

Eleven Coritech AC bi-directional EVSE were installed and commissioned for use with the VIA vehicles. Five Coritech AC bi-directional EVSE were procured to service five planned EVAOS vehicles. Two of those EVSE were installed and commissioned, with the remainder placed in storage. At the conclusion of the PEV-V2G program, PEV-V2G team performed minor modifications to permit the installed Coritech AC EVSE to operate in uni-directional charge-only mode.

2.1.4.3 Coritech DC EVSE

Figure 15 shows a Coritech SAE-compliant DC EVSE installed at LAAFB. These charging stations are rated at 50 kW and interfaced to the grid through a 480 V 3-phase connection. These charging stations connect to the vehicles through an SAE J1772 Combo connector, which has pins for DC current rated up to 500 volts direct current (VDC), 200 Amps (100 kW maximum). Coritech DC bi-directional EVSE were installed and commissioned for use with the EVI and Phoenix vehicles for the demonstration. The Coritech DC EVSE remained in use in support of the Phoenix bus at the conclusion of the program.

Figure 13. PPS DC EVSE with CHAdeMO Interface

Figure 14. Coritech AC EVSE (SAE Level II)

Figure 15. Coritech DC EVSE (SAE Combo)

2.1.5 Software

In response to real-world conditions during the demonstration, several changes were made to the LAAFB OB-EVI subsystems:

- Enhanced the control algorithms of the OB-EVI subsystems which interact with all V2G-capable PEVs and charging stations.
- Implemented software enhancements to manage cell balancing of VIA vans, EVI trucks and the Phoenix bus:
    - Restricted maximum vehicle SOC for the purpose of disabling cell balancing until opportune moments which aligned with driving and V2G missions. The vehicle SOC threshold above which cell balancing occurs was established as 94%.
    - Scheduled and executed cell balancing at coordinated times.

2.1.6 Telemetry

Site telemetry is required at LAAFB by Southern California Edison (SCE), because the PEV-V2G system caused total existing and planned power production to exceed one megawatt. SCE granted V2G startup/demonstration at LAAFB with the understanding that the DoD would install telemetry as required. Leveraging its knowledge of the PEV-V2G infrastructure and operations and relationships with LAAFB, V2G support contractors and SCE, the PEV-V2G team began design and implementation of an enterprise-wide energy monitoring telemetry system that meets the requirements of SCE and LAAFB. In addition, the team began associated C&A efforts required by the Air Force Civil Engineering Center (AFCEC) for telemetry design approval. These efforts continued through the completion of the V2G demonstration. Upon future approval by AFCEC, the telemetry system can be connected to appropriate metering devices for implementation.

2.2 JB Andrews

The JB Andrews demonstration fleet consisted of eight Nissan LEAFs connected to PPS EVSE charging stations controlled by OB-EVI software developed by Kisensum. The JB Andrews electric vehicle parking lot and portion of the PEV fleet is shown in Figure 16.

Figure 16. JB Andrews EV Lot

2.2.1 Utility/Regulatory

PJM Interconnection is an RTO that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia. The PEV-V2G program participated in PJM's day-ahead regulation market by responding to the RegD (Dynamic) control signal to provide battery power to maintain desired frequency. RegD is intended for fuel constrained, fast-ramping resources, such as batteries, and provides added monetary incentive for performance.

PJM required an authorized Curtailment Service Provider (CSP) to enter bids into the PJM eMarket system. As a PJM member and authorized CSP for PJM, Pepco entered into an agreement with the Air Force to provide PJM market settlement and coordination services to support JB Andrews participation in the PJM day-ahead regulation market. Pepco is a public utility owned by Exelon that supplies electric power to the city of Washington, D.C. and to surrounding communities in Maryland.

Pepco performed all of the functions necessary to conduct market settlements for regulation service provided to PJM and provide net credits to the customer for the regulation provided, less an administrative charge. The services provided include:

- Registration of JB Andrews' generation for participation in the PJM day-ahead regulation market
- Upload of day-ahead schedule of power provided via email by PEV-V2G team to participate in the regulation market
- Preparation of detailed PJM billing from the dedicated Pepco Regulation Market sub account invoice for JB Andrews

- Processing monthly credits as billing line item adjustments on the JB Andrews monthly retail Pepco invoice.

2.2.2 Market Participation

The PEV-V2G program at JB Andrews participated in PJM's day-ahead regulation market by responding to the RegD (Dynamic) control signal, with both regulation up (vehicle discharge) and regulation down (vehicle charge) market participation. The base elected not to utilize the FMS, instead committing the vehicles for use from 4 p.m. to 7 a.m. on weekdays and all day on weekends. Manual processes were employed to assess vehicle availability and submit day-ahead market participation bids.

The following sections discuss: 1) the timeline for entering PJM's ancillary services market and key milestones relative to market participation, 2) total system capacity, and 3) metrics regarding system performance and revenue generated during the demonstration.

2.2.2.1 Significant Milestones

JB Andrews formally entered the frequency regulation market on April 18, 2017. Participation began with conservative steps. Significant milestones of the process follow.

- September 30, 2016 – Successful online tests completed with Pepco and PJM.
- October 3, 2016 – Received PJM market certification.
- October 14, 2016 – Began mock day-ahead bid submissions to establish and validate a daily process of bid submission.
- October 2016–April 2017 – JB Andrews/Pepco contract negotiations.
- April 21, 2017 – First day of successful market participation in the PJM frequency regulation market. Began scaled back weekday-only participation to ensure accurate performance.
- June 6, 2017 – Transitioned to weekday participation of three 3-hour events with 1-hour SOC restoration period between each, for a total of 9-hours of weekday participation, and six 3-hour on / 1-hour off events on weekends for a total of 18-hours of weekend participation, yielding a total of 81 weekly participation hours.

2.2.2.2 Participation Capacity

Unlike LAAFB, the V2G-capable PEV fleet at JB Andrews did not change over the course of market participation. Table 6 shows the vehicle capacity at JB Andrews. Note that, since PJM required bids in increments of 100 kW, bidding was limited to 100 kW to ensure adequate reserve in the event of technical issues.

Table 6. PEV-V2G Vehicle Capacities at JB Andrews

Vehicle Type	Quantity	kW per Vehicle	Total Capacity (kW)
Nissan LEAF	8	30	240

2.2.2.3 Participation Metrics and Revenue

The following metrics reflect JB Andrews system performance through October 18, 2017:

- Average Performance Score, Latest 100 hours – 0.9463.
- Earned credits to-date – $4,728.13.
- Total hours participated – 1,573.

A history of daily market participation hours is provided in Figure 17, participation energy in Figure 18, and revenue information in Figure 19. Since June 6, 2016 when full market participation began, performance matched the goals for hours and energy, with the exception of August 21 when an additional 3 hours was added to take advantage of higher pricing during the total solar eclipse.

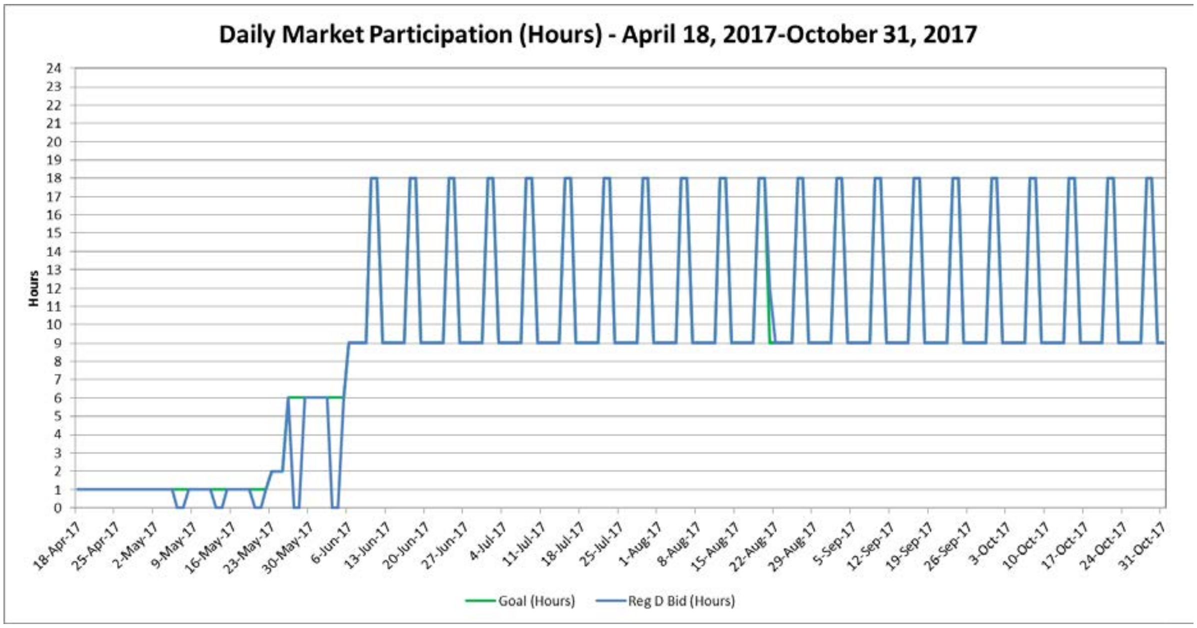


Figure 17. JB Andrews Market Participation Hours

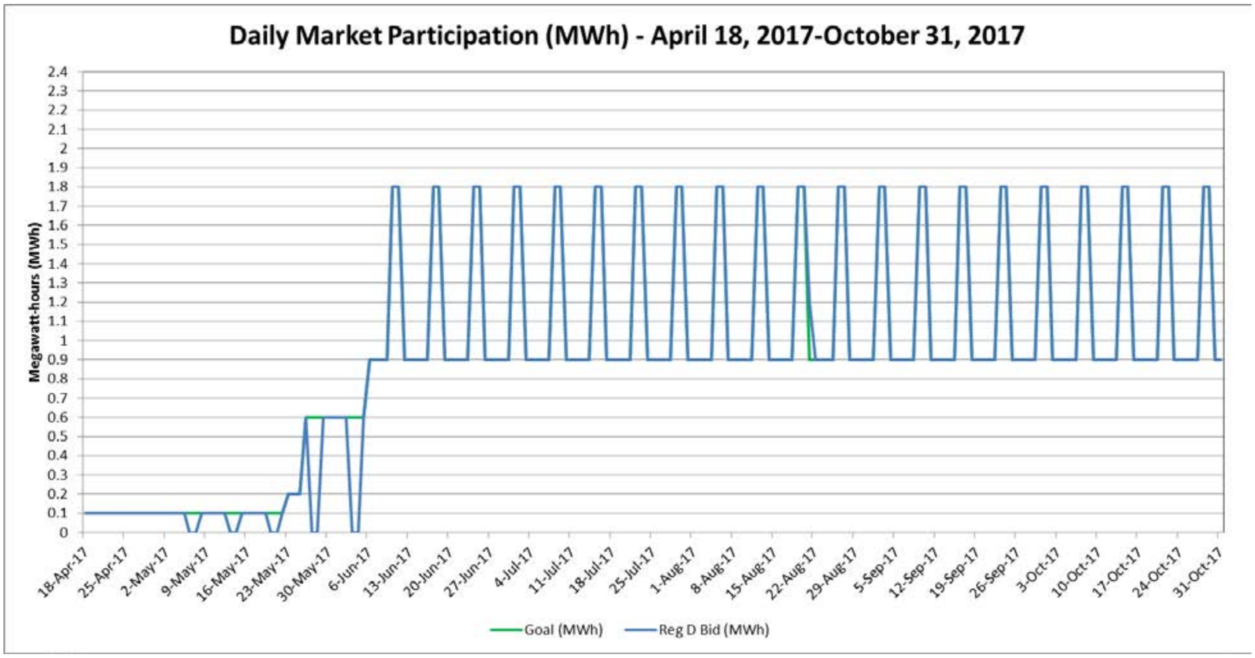


Figure 18. JB Andrews Market Participation Energy

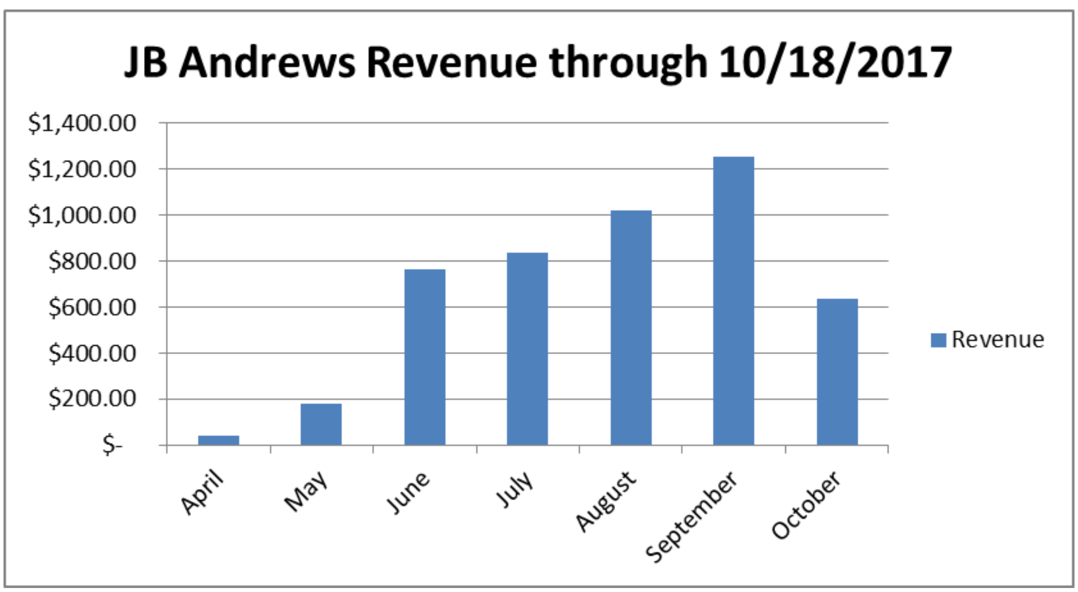


Figure 19. JB Andrews Revenue

2.2.3 Vehicles

The bi-directional PEV fleet at JB Andrews consisted of eight Nissan LEAF sedans. (Planned EVAOS vehicles were not delivered) Nissan LEAFs are a four-door, five-passenger standard model PEV sedan offered by Nissan. They have a driving range of up to 75 miles. Bi-directional power transfer capability is standard on 2013 and later model year LEAFs.

A relatively low amount of mileage was put on the LEAFs during the demonstration. No car was driven more than 1,500 miles, and in many cases vehicles had less than 1,000 miles of driving in over two years. This low usage is not attributed to any reliability issues with the vehicles and is most likely due to low demand and short distance trips when utilized.

The eight Nissan LEAFs will remain as part of JBA's vehicle fleet at the conclusion of the demonstration.

2.2.4 Charging Stations

Eight PPS DC bi-directional EVSE were installed and commissioned for use with the Nissan LEAF vehicles. The PPS EVSE remained in use at the conclusion of the program. Note that unlike PPS stations at other locations, site infrastructure at JB Andrews allowed the PPS EVSEs to operate at their full 30 kW capacity. The eight Nissan LEAF/EVSE pairings were therefore able to provide a collective 240 kW of power transfer capacity for purposes of market participation.

Five Coritech AC bi-directional EVSE were installed for other anticipated vehicles. To support the JB Andrews sustainment efforts, the PEV-V2G team performed minor modifications to permit the EVSE to operate in uni-directional charge-only mode.

2.2.5 Software

The PEV-V2G program goal to implement the same software code at all installations was achieved by developing common software modules that provided vehicular reservation and energy resource management at all installations. The baseline effort was the OB-EVI software developed by Kisensum for LAAFB. However, the GSM module used within OB-EVI at LAAFB was developed by LBNL using a product called Distributed Energy Resources Customer Adoption Module (DER-CAM). While suited for prototype development at LAAFB, this large and expensive application was not appropriate for the other installations in this program. Kisensum therefore developed a replacement module that was used for all other installations.

The development was divided into two efforts—a simple energy scheduler (SES) and a comprehensive energy scheduler (CES). The SES prepared bids during weekends and evenings when vehicles remained connected to the charging stations. The CES implemented a more complex algorithm to support the bidding during active business hours by taking trips and reservations into account. These scheduler modules were implemented and tested but were not deployed at JB Andrews. Minimal fleet driving missions and the simple PJM participation process allowed manually executed bid processes to satisfy the goals of the demonstration.

2.3 Fort Hood

Fort Hood was selected as one of the pilot sites for this demonstration because it is located in the ERCOT ISO region with TXU Energy as its local electric utility. The test fleet consisted of eight Nissan LEAFs connected to PPS EVSE charging stations controlled by OB-EVI software developed by Kisensum. The Fort Hood EV parking lot is shown in Figure 20.

Figure 20. Fort Hood EV Lot

2.3.1 Utility/Regulatory

ERCOT manages the flow of electric power to 24 million Texas customers, representing about 90 percent of the state's electric load. As the independent system operator for the region, ERCOT schedules power on an electric grid for the region. It also performs financial settlement and offers a variety of services to Texas electricity market participants. The PEV-V2G program focused on participation in ERCOT's Fast Responding Regulation Service (FRRS) ancillary services market, in which resources must be able to respond to frequency changes within one second.

Entities who intend to participate in the ERCOT Market to conduct market transactions must be qualified as a Qualified Scheduling Entity (QSE) or establish a relationship with a QSE to provide scheduling, market services and financial settlement with ERCOT. Viridity Energy Inc. (Viridity) is a registered QSE with ERCOT. Viridity entered into an agreement with the Defense Logistics Agency – Energy (DLA-E) to represent the Fort Hood V2G system in the demand response market with ERCOT.

In November 2014, Viridity met with ERCOT personnel to discuss the implementation of FRRS at Fort Hood. The discussion identified two critical issues:

1. Fort Hood's classification as a Load acting as Resource (LaaR) would not permit it to deliver energy to the grid. Only assets registered as "Generating" resources are permitted to do this in ERCOT; however, registration as a "Generating" resource is a costly and lengthy process best suited for multi-megawatt in-front-of-the-meter projects.
2. ERCOT would not allow assets to be dispatched for FRRS Up (discharging vehicle batteries to the grid) and FRRS Down (charging vehicle batteries from the grid) in the same hour. This would force the PEV-V2G system to choose to participate in one

direction or the other for each hour, significantly reducing the financial value of the system.

2.3.2 Simulated Market Participation Test

The Army determined that, without the ability to be properly classified to participate in an ancillary services market, Fort Hood market participation would not be possible under the scope of this program. In order to provide a proof-of-concept for the system, the Army directed that the PEV-V2G team conduct a simulated market participation effort to demonstrate that the system as installed would have been able to participate in the ancillary services market if registration as a Generating resource could have been done cost effectively.

From July 29, 2016 through August 5, 2016, the PEV-V2G team, with the assistance of Viridity, conducted system testing that simulated market participation for both ERCOT and PJM to demonstrate the potential use of the system in multiple markets. Viridity determined that the PEV-V2G system could not meet the FRRS one-second response time because of the four-second response time of the PPS charging stations. Consequently, testing instead simulated ERCOT's Regulation Up and Regulation Down markets.

Eight Nissan LEAF sedans and paired PPS charging stations were utilized to generate the minimum 100 kW of power required to bid into each market. Total system capacity with eight LEAFs at 15 kW each was 120 kW. The OB-EVI system received an ISO-specific power dispatch signal from Viridity via digital communications over the Internet and charged/discharged the vehicle fleet as needed to satisfy the dispatch signal commands.

- ERCOT Qualification Test – A system must achieve the commanded capacity within five seconds and maintain capacity for 50 seconds. The PEV-V2G system at Fort Hood passed the ERCOT Qualification Test.
- PJM Qualification Test – A system must follow a live PJM RegD signal for 60 minutes with a performance score of 93% and a published Qualification Test signal for 40 minutes with a performance score of 93%. The PEV-V2G system at Fort Hood passed the PJM Qualification Test with a 96% performance score with each signal.

Viridity found that the fleet of eight LEAFs was capable of passing the market qualification tests and performed well in simulated market trials for both ERCOT and PJM markets. If Fort Hood would decide to enter the market, Viridity indicated it "would have no reservations representing this system in the ERCOT Regulation Up and Regulation Down markets. However, a larger fleet of vehicles would increase schedule flexibility. With the current fleet, all eight vehicles would be required to meet the market minimum bid of 100 kW. Coordination of vehicle availability would be a key success factor for a fleet of this size to successfully participate in Ancillary Service markets."

2.3.3 Vehicles

Two types of bi-directional PEVs were utilized at Fort Hood. The manufacturers for these two PEV types were EVAOS and Nissan. PEV models and quantities are shown in Table 7 along with vehicle type (PEV or PHEV).

Table 7. PEV-V2G Vehicles at Fort Hood

Manufacturer	Model	Vehicle Quantity	Vehicle Description
Nissan	LEAF	8	Model Year 2013 Sedans; PEV
EVAOS*	F-150	10	F-150 XL, Crew Cab trucks modified with EVAOS plug-in electric hybrid aftermarket modification

*The Ford F-150 trucks modified with EVAOS kits were able to participate in limited driving missions.

Figure 21 shows one of the Nissan LEAFs at Fort Hood. The LEAF fleet saw regular usage on day trips to nearby locations. The eight LEAFs passed ERCOT market qualification tests and will remain part of Fort Hood's vehicle fleet at the conclusion of the demonstration.

Figure 21. Nissan LEAF at Fort Hood

Fourteen F-150 trucks were leased from GSA, of which ten were modified with EVAOS components into PHEVs. The EVAOS-modified trucks were used for a limited number of driving missions and were not used in Fort Hood's simulated market testing. The PEV-V2G team performed a system removal of the EVAOS kits from the F-series trucks near the conclusion on the demonstration, restoring the trucks to stock condition. The trucks were then returned to Fort Hood as standard GSA leased vehicles.

2.3.4 Charging Stations

Eight PPS DC bi-directional EVSE were installed and commissioned for use with the Nissan LEAF vehicles. All PPS EVSE remained in use at the conclusion of the program.

Fourteen Coritech AC bi-directional EVSE were installed for EVAOS vehicles. When the EVAOS vehicles were no longer used, these stations were converted for uni-directional use by the PEV-V2G team, providing Fort Hood with additional PEV charging capacity for future use.

2.4 JB MDL

JB MDL was designated as one of the pilot sites for this demonstration because it is located in the PJM RTO with First Energy as its local electric utility. The JB MDL electric vehicle parking lot is shown in Figure 22.

Figure 22. JB MDL EV Lot

2.4.1 Vehicles

Although JB MDL was extremely motivated and supportive of participating in V2G, no PEV vehicles were delivered to JB MDL for this demonstration. In the original demonstration plan, eight Ford F-series trucks were leased from GSA for use in the demonstration. These F-series trucks were planned to be modified with EVAOS systems, converting them to PHEVs for use in the JB MDL V2G demonstration fleet. However, as EVAOS trucks were not able to participate in the demonstration, the leased trucks were returned to the base vehicle pool in original condition. Alternative vehicles meeting base mission requirements were not available to allow JB MDL to engage in V2G market participation.

2.4.2 Charging Stations

Eight Coritech AC bi-directional EVSE were originally installed and intended for use with the EVAOS vehicles. The PEV-V2G team performed minor modifications to permit the EVSE to operate in uni-directional charge-only mode and installed additional EVSE to position JB MDL for future PEV use.

3.0 COST-BENEFIT ANALYSIS (CBA)

A cost-benefit analysis (CBA) was conducted to determine if PEV-V2G technology could provide a positive financial benefit compared with conventional vehicles. For purposes of this summary, discussion will be limited to usage of the Nissan LEAF sedans and the Phoenix Shuttle. These vehicles participated most frequently and reliably in the market during the demonstration and therefore are most likely to be chosen for future fleets.

The CBA evaluated current V2G investment and benefits and concluded that, under current market conditions, the PEV-V2G program could not be justified on cost savings alone. High infrastructure and equipment costs coupled with the low market revenue make this impossible. However, measuring the true cost of technology adoption balances implementation and sustainment costs with the derived benefits. Numerous intangible program benefits also exist and should be part of the implementation decision. The analysis also evaluated what factors are needed to make a successful business case.

3.1 Infrastructure Costs

Development of a hypothetical fleet scenario (20 vehicles at JB Andrews) early in the program provided a means to estimate implementation impact. Demonstration data used for the CBA included infrastructure, communication, vehicle procurement, vehicle modification, EVSE and training costs. Software costs needed for scheduling and competing in the electrical utility ancillary services markets were included. Open source research supplemented the demonstration data and provided a means to estimate the emission impact of PEV-V2G implementation.

The infrastructure and equipment needed for PEV-V2G vary in lifespan. Their costs were annualized so a comparison can be made. Annualized infrastructure and communication costs were over $40,000 for the hypothetical fleet. Annualized costs for the charging stations were over $85,000. The cost model developed for the analysis clearly shows the investment costs cannot be recouped solely through reductions in operations and maintenance (O&M) costs and revenue generation from the ancillary services market.

These costs, however, were part of a development project and do not represent post-commercialization costs. In addition, knowledge from this project will allow infrastructure to be more efficiently designed and implemented thereby reducing some costs. High cost items including infrastructure, equipment costs and software procurement/maintenance costs contributed greatly to the inability to reach cost parity at this time, resulting in the conclusion that driving down these infrastructure and equipment costs is key to achieving cost parity.

At this point, the CBA focus switched from measuring the progress toward cost parity to quantifying the sustainment impact of the PEV-V2G program. This approach provides insight into future sustainment costs at military installations once there is a reduction in implementation costs.

3.2 Operating Costs and Benefits

There are cost savings and environmental benefits of utilizing a PEV-V2G fleet. The usage of PEV vehicles over ICE provides a savings in energy costs. There are energy cost savings associated with the use of electricity compared to gasoline. Electricity is more environmentally friendly, reducing carbon dioxide (CO_2) emissions. Maintenance costs of PEVs are also generally lower as compared to ICE vehicles. Finally, participation in the ancillary services market can generate revenue.

Table 8 below provides the energy and environmental savings per mile for the LEAF and Phoenix demonstrations. Data collection occurred during a one-year demonstration period for both sites. This analysis shows that the program did accomplish several of its main objectives—reductions in energy costs, petroleum use and GHG emissions. Utility records and local gasoline prices provided estimates of electricity and gasoline costs. Anticipated fuel usage for equivalent conventional vehicles (2014 Nissan Sentra and 2012 Ford E350 Starcraft shuttle bus) was used to calculate petroleum reduction. Evaluation of the program drivers provides a measure of how successful the program was in meeting established goals.

Table 8. PEV-V2G Implementation Impact on Program Drivers

Vehicle	Annual Mileage	Energy Savings ($/mile)	Annual Fleet Energy Savings	Petroleum Reduction (gallons)	Annual GHG Emission Reduction (pounds CO_2)
LAAFB					
Nissan LEAFs (13)	23,840	$0.056	$1,374	795	12,119
Phoenix Bus (1)	7,372	$0.10	$737	737	8,371
Total	**31,212**		**$2,111**	**1,532**	**20,490**
JB Andrews					
Nissan LEAFs (8)	**971**	**$0.05**	**$53**	**32**	**341**

The cost of operation of the selected PEV-V2G fleet was calculated using demonstration data. Operational costs included energy costs and maintenance costs of the vehicles and the charging stations. Anticipated revenue generation for the vehicle fleet reduces the actual cost to operate. Note that revenue generation is a projection based on the assumption the vehicles would participate in the ancillary services market for a large portion of the time when not in use. In addition, for LAAFB, California has a low carbon fuel standard (LCFS) in place, which results in a “credit” being applied to their electricity bill due to offsetting fuel carbon emissions. This credit amounted to almost $3,000 during the demonstration period. The results indicate the LEAF fleet would generate more revenue than the operating costs with the net operating savings of $9,500. The Phoenix Bus would increase operating costs by over $10,000 for one vehicle, primarily due to its high charging station and vehicle maintenance costs. However, this vehicle is still a prototype, and these costs should be reduced with commercialization. Table 9 below summarizes these results.

Table 9. Annual Fleet Costs

Vehicle	Annual Cost to Operate PEV	Annual Cost to Operate PEV-V2G (Charging Stations)	LCFS Credit	Anticipated Revenue Generation	Actual Annual Cost to Operate
LAAFB					
Nissan LEAFs (13)	$878	$4,400	$1,914	$12,864	($9,500)
Phoenix Bus (1)	$4743	$10,000	$835	$3,300	$10,608
Total	**$5,621**	**$14,400**	**$2,749**	**$16,164**	**$1,108**
JB Andrews					
Nissan LEAFs (8)	**$242**	**$4,642**	**NA**	**$9,310**	**($4,668)**

The CBA also determined that potential revenue generation was not as high as anticipated. To date, the utilities charge significant monthly fees ($780-$1,000) to participate in the ancillary services market, and these were not included analysis. As noted above, JB Andrews could expect around $9,300 dollars per year in revenue (for its current 8-vehicle fleet). Extrapolating this to the hypothetical 20-vehicle fleet used for the CBA would result in an estimated $23,250 per year in revenue. Since the PEV-V2G program had over $120,000 ($40,000 for infrastructure and communications and $85,000 for charging stations) in annualized infrastructure and equipment costs, a positive scenario for payback is unlikely. However, these costs were based on a DC charging station used for the LEAFs, which at the time of the project was four times the cost of AC charging stations.

To develop a positive business case, several factors would be of key importance:

- Reduce infrastructure and equipment costs.
- Derive more value from using the vehicles in multiple modes as energy assets:
    - Peak demand reduction
        - Frequency regulation.
        - Reactive power and voltage control.
- Implement changes to regulatory and utility company policies:
    - Aggregate different fleet locations into one market account to reduce utility fees.
    - Reduce or eliminate the utility companies' monthly fees to encourage participation.

3.3 Qualitative Analysis of Non-Financial Benefits

In addition to the short-term cost impact, there are long-term beneficial impacts from this V2G development effort. These impact types are often difficult or impossible to quantify simply with dollar values. A qualitative assessment delineates additional impacts, which are crucial to choosing the best investment alternatives.

The military has a high priority to reduce energy security risks through effective energy security planning and infrastructure investment. PEV-V2G technology can contribute towards an installation's ability to perform its essential functions should there be a grid outage. PEV-V2G enables the opportunity to optimize system performance and achieve additional benefits for the installation, such as improved efficiency and lower energy cost.

There are also benefits to government involvement in technology development. The primary goal of PEV use in California is the de-carbonization of the atmosphere through GHG reduction. Incentives and policy structure in California have been successful in promoting PEV implementation. There is some consensus among PEV-V2G promoters that if governments invest in electric vehicles, the manufacturers will develop the equipment and the utilities will build the needed infrastructure.

The intangible benefits of the PEV-V2G program identified under this effort include:

- Advancing technologies for national, state, and local energy assurance.
- Improving ability to provide storage and demand response to integrate renewables.
- Improving ability to manage energy flow to and from the electrical grid.
- Strengthening relationships and partnering with electric regulating authorities and community to meet future requirements.
- Paving path for smaller generation sites to enhance energy assurance
- Supporting grid stability.
- Future capability for LAAFB resiliency/islanding, assurance.
- Fulfilling EO 13693 - Sustainability
    - Decrease petroleum consumption
    - Reduce GHG emissions.

However, there are also risks with any technology implementation. PEVs are primarily for transportation, and a V2G application must not limit their availability when needed for their primary mission purpose. There are complexities with the V2G technologies related to the communications, metering, verification, protection and control systems. In addition, impact on the vehicles batteries from additional V2G cycling (charging and discharging) may result in a loss of efficiency and shortening of battery life. This efficiency loss may affect GSA's willingness to allow their vehicles for V2G applications. PEV batteries will also be competing against stationary batteries and other resources in the ancillary services market and this competition may reduce their future value. Finally, the potential exists with PEV charging during the day (such as work-based charging stations) that daytime over-generation may occur, reducing its value to the utility.

The PEV-V2G demonstration illustrated the benefits and barriers to military implementation. The main conclusion is current market conditions prohibit the justification of PEV-V2G implementation on strictly an economic basis. This will be true unless there is a large reduction in infrastructure costs. However, expanding the analysis to include the intangible benefits discussed in this report may justify further implementation at this time.

4.0 PEV-V2G PROGRAM RESULTS

The primary objective of the PEV-V2G program was to implement, test and demonstrate V2G technologies and conduct PEV-V2G demonstrations at the four pilot sites—LAAFB, JB Andrews, Fort Hood and JB MDL. The overall goal of this program was to demonstrate the V2G system and collect and analyze data quantifying the impact of V2G implementation in differing environments and energy markets.

The following sections summarize the results of the PEV-V2G program, including: 1) the technology readiness of V2G equipment, 2) the equipment maturity and reliability observed at the pilot locations, 3) a comparison of the V2G demonstrations conducted at each site, and 4) a comparison of the ancillary services markets in the V2G demonstrations.

4.1 Technology Readiness

A V2G system is technically complex to implement, as many supporting technologies are not fully commercialized. The PEV-V2G program was initiated to advance the technology, equipment and collaborations necessary to allow DoD to adopt V2G technology. The overall goal was to identify and further technologies that will bring the costs of a PEV fleet in line with a conventional vehicle fleet.

Although the PEV-V2G program proved V2G works, it also demonstrated that few of the components were fully mature, defined as products readily available in the marketplace with a history of satisfied customers. The program featured equipment primarily provided by small businesses, which learned achieving bi-directional capabilities was more challenging than envisioned. It is estimated that this technology is still several years away from being fully commercialized.

This program significantly advanced the technology readiness levels (TRLs) of several bi-directional power systems (see Appendix A for TRL definitions). PPS charging stations were increased from TRL 5 to TRL 8, and Coritech systems from TRL 5 to TRL 7.

4.2 System Maturity/Reliability

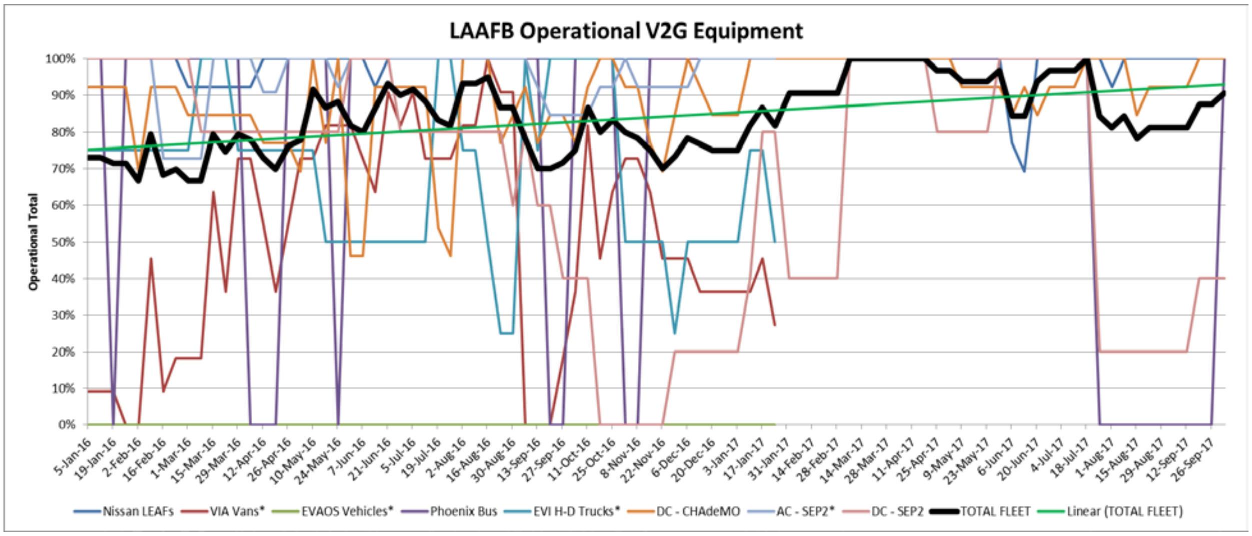
The system maturity and reliability of many V2G-capable PEVs, charging stations and V2G support equipment significantly improved throughout the PEV-V2G program. The following sections show the reliability data collected during the program for each vehicle, charging station and major program component for each pilot location.

4.2.1 LAAFB

Figure 23 shows the operational trend improvements for LAAFB since January 2016. Key take-aways are as follows:

1. The Nissan LEAFs were the most reliable PEVs in the fleet.

2. The reliability of the Phoenix bus, Coritech DC EVSE and PPS EVSE increased in the latter portion of the program.
3. The overall reliability of the LAAFB fleet increased by 17% over the course of the program.



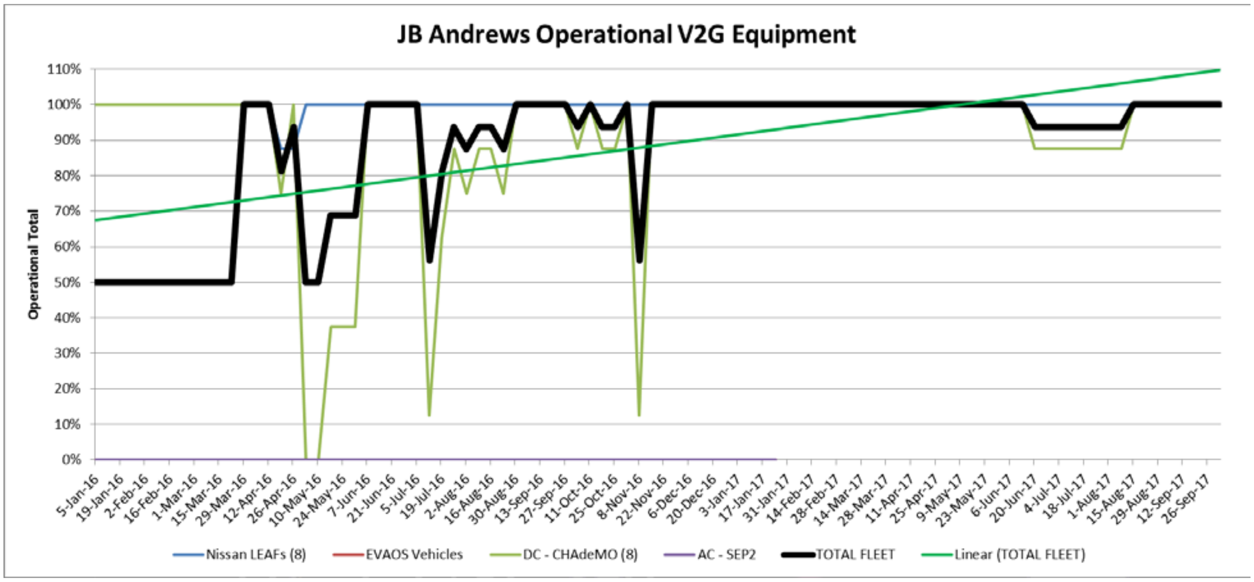
As of 3/29/2016, EVAOS totals were removed from all calculations. As of 2/1/2017, VIA, EVI and AC – SEP2 totals were removed from all calculations.

Figure 23. LAAFB Operational Trend Data

4.2.2 JB Andrews

Figure 24 shows the operational trend improvements for JB Andrews since January 2016. Key take-aways are as follows:

1. The Nissan LEAFs were extremely reliable PEVs throughout the program.
2. The reliability of the PPS EVSE increased in the latter portion of the program.
3. The overall reliability of the JB Andrews fleet increased by 32% over the course of the program.



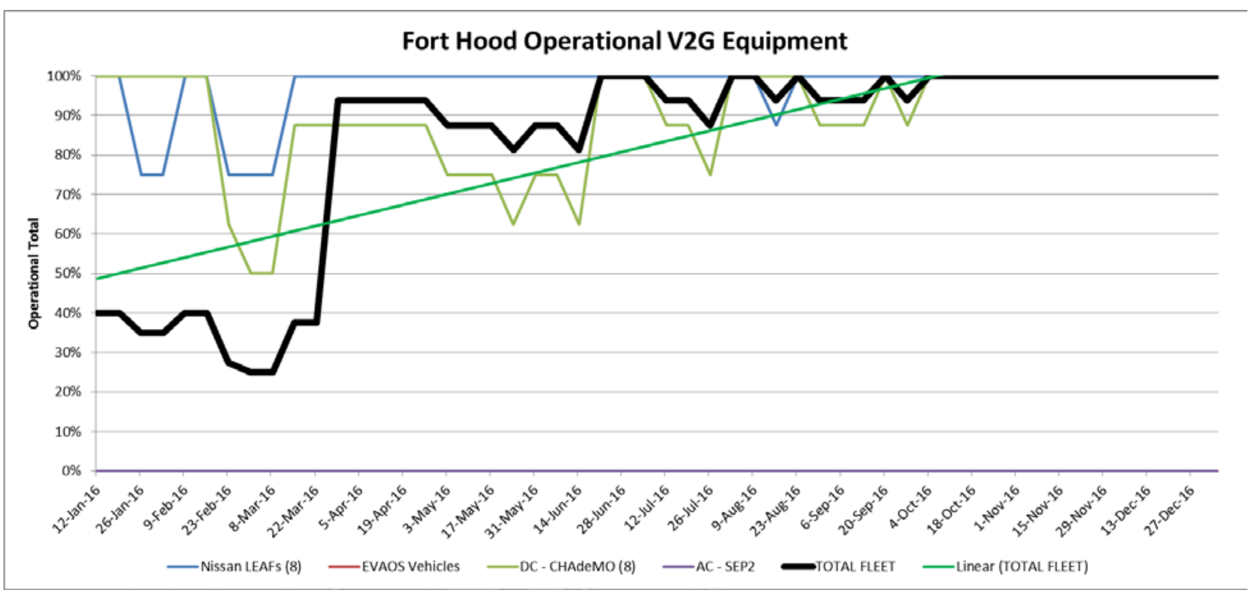
As of 3/29/2016, EVAOS and associated EVSE totals were removed from all calculations.

Figure 24. JB Andrews Operational Trend Data

4.2.3 Fort Hood

Figure 25 shows the operational trend improvements for Fort Hood since January 2016. Key take-aways are as follows:

1. The Nissan LEAFs were extremely reliable PEVs throughout the program.
2. The reliability of the PPS EVSE increased in the latter portion of the program.
3. The overall reliability of the Fort Hood fleet increased over 50% during Fort Hood's active participation in the program.



As of 3/29/2016, EVAOS and associated EVSE totals were removed from all calculations.

Figure 25. Fort Hood Operational Trend Data

4.2.4 JB MDL

JB MDL charging station equipment was installed but not commissioned for V2G operations, and no data was collected.

4.3 Demonstration Comparison

Table 10 provides a comparison of each demonstration. The following sections summarize the results of each demonstration.

Table 10. Demonstration Comparison

Criteria	LAAFB	JB Andrews	Fort Hood	JB MDL
V2G-capable Infrastructure	Yes	Yes	Yes	Yes
V2G-capable Vehicles	Yes	Yes	Yes	No
Bi-directional EVSE	Yes	Yes	Yes	No
OB-EVI Server Installed	Yes	Yes	Yes	Yes
OB-EVI Software Installed	Yes	Yes	Yes	No
FMS to Reserve Vehicles	Yes	No	No	No
Regional Energy Organization	CAISO	PJM	ERCOT	PJM
CSP / QSE / SC	SCE	Pepco	Viridity	Viridity
Market Participation	Yes	Yes	Simulated	No

4.3.1 LAAFB

LAAFB conducted a fully automated V2G demonstration in two phases—1) with both regulation up (vehicle discharge) and regulation down (vehicle charge) market participation under control of a CAISO dispatch signal from December 18, 2015 through January 26, 2017 and 2) regulation up only from January 27, 2017 through September 30, 2017. The FMS, used to create vehicle reservations and schedule vehicles for trips, was fully integrated into the base's standard operating procedures. This allowed both the fleet manager and the PEV-V2G control software to maintain cognizance of the charge state of each PEV battery, as well as the range capabilities of each PEV at all times to dispatch vehicles properly. The PEV-V2G control software used its understanding of base mission requirements, vehicle availability, battery capacity and SOC, historical day-ahead pricing and ancillary services market requirements to automatically create and submit day-ahead bids for the CAISO market and satisfy CAISO awards.

4.3.2 JB Andrews

JB Andrews conducted a semi-automated V2G demonstration, with both regulation up (vehicle discharge) and regulation down (vehicle charge) market participation under control of a PJM dispatch signal. The base elected not to utilize the FMS, instead committing the vehicles for use from 4 p.m. to 7 a.m. on weekdays and all day on weekends. Manual processes were employed very successfully to assess vehicle availability and submit day-ahead market participation bids. Based on an assessment of early market participation results, final participation totaled 9 hours on weekdays and 18 hours on weekends, with each three-hour V2G segment followed by a one-hour charge segment.

4.3.3 Fort Hood

Fort Hood installed and implemented all needed V2G infrastructure, equipment and software and conducted simulated market testing due to current ancillary services market challenges. Simulation met Army goals by proving system performance and enabling future options. The Fort Hood PEV-V2G system passed the ERCOT Qualification test for the Regulation Up and Regulation Down markets, with eight Nissan LEAFs and paired PPS charging stations properly responding to a simulated dispatch signal.

4.3.4 JB MDL

JB MDL did not conduct a V2G demonstration, as no V2G-capable vehicles were delivered.

4.4 Market Comparison

The PEV-V2G program incorporated three regional energy organizations and multiple ancillary services markets. LAAFB achieved commercial operation in the CAISO market on December 18, 2015 and participated until September 30, 2017. JB Andrews began market participation in the PJM market on April 21, 2017 and continues to participate as of the writing of this report. From July 29, 2016 through August 5, 2016, Fort Hood simulated participation in the ERCOT market and gained an understanding of qualification, participation and performance criteria. Table 11 presents a market comparison based on the experiences of the PEV-V2G program. All factors considered, the PJM market was the most favorable for a research, development, test and evaluation (RDT&E) pilot program.

- PJM qualification capacity is substantially less than CAISO.
- The PJM minimum accuracy requirements are more lenient than CAISO.
- Monthly revenue was significantly higher for JB Andrews (PJM) than LAAFB (CAISO), even though the fleet size at LAAFB was much larger.
- Note that although LAAFB had more LEAFs, the most reliable vehicle type, they were restricted to a charge/discharge rate of 15 kW due to LAAFB infrastructure limitations, while LEAFs at JB Andrews were allowed to charge/discharge at 30 kW.

Table 11. Market Comparison

Criteria	LAAFB	JB Andrews	Fort Hood
Regional Energy Organization	CAISO	PJM	ERCOT
CSP / QSE / SC	SCE	Pepco	Viridity
Market Participation	Yes	Yes	Simulated
Ancillary Services Market(s)	Reg Down (charge), Reg Up (discharge)	RegD (charge and discharge)	Reg Down (charge), Reg Up (discharge)
Time to Market Entry	3 years	3 years	N/A
Qualification Capacity	500 kW (charge and discharge)	100 kW	100 kW
Minimum Bid	100 kW	100 kW	100 kW
Bidding Process	Bid and Award	Bid Only	Bid and Award
Minimum Accuracy Score	25% (monthly)	40% (rolling 100-hour)	No
Performance Penalty Fees	Yes	No, reduced performance score	Yes
One-time Setup/Survey Fees	Yes	Yes	Yes
Monthly Administration Fees	Yes	Yes	Yes
Actual Hours of Participation	5/1/16 – 9/30/17: Reg Up/Down – 1,128 Reg Up Only – 1,030 Total – 2,158	4/21/17 – 10/18/17: Reg Up/Down: 1,319	N/A
System Capacity from LEAFs	13 LEAFs @ 15 kW = 195 kW	8 LEAFs @ 30 kW = 240 kW	8 LEAFs @ 15 kW = 120 kW
Total System Capacity	5/1/16 – 1/31/17: 549 kW 2/1/17 – 9/30/17: 235 kW	240 kW	120 kW
Actual Revenue (without fees)	$7,639 (17 months) $449/month	$4,728 (6 months) $788/month	N/A

5.0 CONCLUSIONS AND RECOMMENDATIONS

The PEV-V2G program has enabled the DoD to successfully demonstrate bi-directional non-tactical electric vehicle fleets at multiple locations. V2G-capable PEVs met rigorous military, industry and utility standards, enabling DoD installations to compete in the energy ancillary services market. Others have tested the V2G concept, but the PEV-V2G project was novel in size, scale, and daily use of assets for mission support.

The following sections examine the program successes, benefits, implementation barriers, risks and lessons learned as a result of the demonstration.

5.1 Program Successes

Since its initiation in 2011, the PEV-V2G program has made great strides in advancing the technology, equipment and collaborations necessary to allow DoD to adopt V2G technologies.

Under previous contracts, the PEV-V2G team successfully:

- Validated a model for deploying V2G-capable PEVs with an associated charging infrastructure system.
- Validated a V2G fleet management software system with appropriate cyber-security certifications.
- Identified best practices for integrating V2G-capable PEVs into DoD's non-tactical ground fleet.
- Identified best practices for utilizing V2G-capable PEVs to support installation energy surety.
- Paved the way for participation in energy ancillary service markets with V2G services.

Under the Demonstration task, the PEV-V2G team successfully:

- Advanced the technology readiness levels (TRLs) of bi-directional power systems (see Appendix A for TRL definitions)
    - o PPS charging stations – TRL 5 to TRL 8
    - o Coritech – TRL 5 to TRL 7.
- Developed power system infrastructure that improved energy resiliency and assurance and enabled market participation.
- Learned how to participate in CAISO, ERCOT and PJM markets.
- Readied DoD and national stakeholders for revenue stream generation through energy ancillary services market participation.
- Quantified V2G vehicle/equipment technology capabilities.
- Identified successful performers.

Under the PEV-V2G program, V2G-capable assets were deployed at four pilot sites. Software was developed to manage the vehicle fleets and provide revenue through the energy ancillary services market. And participation was simulated in the ERCOT market and successfully established in the CAISO and PJM markets.

5.2 Benefits

The PEV-V2G program has provided many benefits to the DoD, including:

- Maximizes the use of underutilized vehicle assets by using the batteries as an energy source.
- Reduces installation energy and fleet vehicle costs.
- Reduces local GHG emissions associated with liquid-fuel vehicles
- Lowers environmental risk from petroleum processing, transportation, and spillage.
- Advances the state of PEVs and charging stations.
- Advances the state of V2G engineering and software applications.
- Stimulates cooperativeness with utility operators and regulators to embrace an alternative energy solution.
- Increases grid energy storage capacity.
- Promotes energy surety across the nation while decreasing dependence on foreign oil.

Intangible benefits identified under this effort include:

- Pilots new national energy security capabilities.
- Advances technologies for national, state, and local energy assurance.
- Strengthens relationships and partnering with electric regulating authorities and communities to meet future requirements.
- Paves a path for smaller generation sites to enhance energy assurance.
- Supports California grid stability.
- Provides a future capability for LAAFB energy resiliency/islanding and assurance.
- Supports Executive Order 13693 – Sustainability
    - Decreases petroleum consumption
    - Reduces GHG emissions.
- Supports California Vehicle-Grid Integration Roadmap Track 3, “Support Enabling Technology Development” through research, development and demonstration.

5.3 Implementation Barriers

While the PEV-V2G program offers notable benefits, the following barriers to V2G implementation have become evident:

- Implementation of V2G technologies requires a significant upfront investment in the vehicle, EVSE and base infrastructure.

- Although the PEV-V2G program has proven V2G works, it also demonstrated that few of the components were fully mature, defined as products readily available in the marketplace with a history of satisfied customers. This may result in a significant number of high-cost O&M issues that must be resolved to keep the equipment and system functioning.

- The program further revealed the need to change the rules and policies of regulators to allow V2G to be implemented. Market entry and qualification requirements can be substantial hurdles to overcome. Fees and penalties can reduce revenue potential, negating the possibility of cost parity.
- The DoD software C&A process is cumbersome and time consuming, especially achieving required government approvals, potentially negatively affecting deployment schedules. The costs associated with the overall C&A process are significant, as well as additional cost impacts due to mandated, ongoing cybersecurity maintenance requirements.

5.4 Risks

The risks associated with PEV-V2G technology implementation include the following:

- PEVs are procured primarily for transportation, and a V2G application must not limit their availability when needed for their primary purpose.
- V2G technology is immature and may result in unavailability of PEVs due to increased maintenance requirements.
- Complexities with V2G technologies related to communications, metering, verification, protection and control systems may not be easily overcome.
- The impact on vehicle batteries from additional cycling (charging and discharging) has not been adequately quantified but is expected to result in a loss of efficiency. This efficiency loss may impact GSA's willingness to allow its vehicles to be used for V2G applications. PEV batteries will also be competing against stationary batteries and other resources, and this competition may reduce their future value.
- The potential exists with PEV charging during the day (such as work-based charging stations) that daytime over-generation may occur, reducing its value to the utility.
- Electricity is a commodity in the ancillary services market, and future market processes are not known. The possibility exists that the market could become saturated eliminating the potential for revenue generation.

5.5 Lessons Learned

The V2G demonstration provided many lessons learned regarding the cost, maturity and reliability of V2G technologies and the policies needed to support participation in ancillary services markets.

- To achieve cost parity with conventional vehicles, a large vehicle fleet is needed to offset V2G overhead costs.

- In some RTO/ISOs, the implementation services costs and monthly fees greatly reduce the value of the monthly revenue.
- Cost parity can only be achievable after V2G equipment is fully commercialized.
- More value must be derived from using V2G-capable vehicles as an energy asset.

- A thorough understanding of RTO/ISO ancillary services market requirements is needed.
  - RTO/ISO requirements will affect commercialization.
  - Each RTO/ISO has its own defined process for marketplace entry; in general, entry will take at least 18-24 months.
  - Not all RTOs/ISOs offer an ancillary services market and prices vary between markets.

- Determine pilot capacity and associated vehicle portfolio by first aligning with installation usage and mission requirements.
  - Vehicle choice drives EVSE selection, which drives infrastructure design.
  - Minimum capacity requirements will differ by RTO/ISO territory.
  - Vehicle power delivery must meet ISO requirements to participate in the market.
  - Vehicle battery cell balancing requirements and performance impacts must be fully understood.

- Expect V2G technologies to mature and standards to evolve.
  - The PEV-V2G program used mainly first-generation products with no field track record.
  - V2G is a new concept, and some RTO/ISOs' processes need to be modified to facilitate the inclusion of RDT&E programs as distributed energy resources.
  - The PEV-V2G program produced and standardized (to the extent possible) interfaces between bi-directional charging stations and PEVs.

- Recognize the DoD's certification and accreditation process will affect deployment schedules.
  - IATT certifications, GIG waivers, and ATO certifications are some of the critical milestones.
  - Resource availability must be assured for continuous cybersecurity needs.

5.6 Recommendations

The PEV-V2G program has demonstrated that, under the right conditions, V2G can be technologically viable and revenue generating. Because V2G systems are technically complex to implement, most V2G equipment lacks sufficient technology readiness, and the nature of ancillary services markets is not user-friendly, an organization should only initiate a V2G pilot after the following criteria are met:

1. V2G-capable vehicles, charging stations and V2G support equipment are fully commercialized and proven reliable.
2. A large enough vehicle fleet can be implemented to offset V2G overhead costs.
3. RTO/ISO and local utility requirements are fully understood, and conditions are favorable for potential revenue capabilities.
4. Options for aggregating pilots within an RTO/ISO under one CSP / QSE / SC are fully investigated (e.g., DoD pilots aggregating under DLA-E as the scheduling coordinator).
5. Ancillary services operating parameters and fee structures are modeled before purchasing assets.

APPENDIX A:
TECHNOLOGY READINESS LEVELS

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology’s basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include “high-fidelity” laboratory integration of components.	Results from testing laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the “relevant environment” differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?

6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

>=	greater than or equal to
%	percent
AC	alternating current
AFB	Air Force Base
AFCEC	Air Force Civil Engineer Center
AFRL	Air Force Research Laboratory
AFV	alternative fuel vehicle
AGC	Automatic Generation Control
APTO	Advanced Power and Technology Office
ATO	Authority to Operate
C&A	certification and accreditation
CAISO	California Independent System Operator
CBA	Cost-Benefit Analysis
CCM	Charge Control Module
CDRL	Contract Data Requirements List
CO2	carbon dioxide
COD	Commercial Operation Date
Coritech	Coritech Services, Inc.
CSP	Curtailment Service Provider
CTC	Concurrent Technologies Corporation
cu ft	cubic feet
DA	day-ahead
DC	direct current
DER-CAM	Distributed Energy Resources Customer Adoption Module
DISA	Defense Information Security Agency
DLA-E	Defense Logistics Agency – Energy
DoD	Department of Defense
DT&E	developmental test and evaluation
E2T	Environmental and Energy Technologies
EIM	EVSE interface module
ERCOT	Electric Reliability Council of Texas
ESM	Energy Storage Module
EV	electric vehicle
EVAOS	Electric Vehicle Add-On Systems, Inc.
EVI	Electric Vehicles International LLC
EVSE	electric vehicle supply equipment
FERC	Federal Energy Regulatory Commission
FMS	Fleet Management System
Ford	Ford Motor Company
FRRS	Fast Responding Regulation Service
GHG	greenhouse gas
GIG	Global Information Grid
GSA	General Services Administration
GSM	Grid Scheduling Module

HA	hour ahead
HPGP	Home Plug Green PHY
Hz	hertz
IASO	Information Assurance Security Officer
IATO	Interim ATO
IATT	Interim Authority To Test
ICE	internal combustion engine
IIM	ISO Interface Module
ISO	Independent System Operator
JB	Joint Base
kW	kilowatt
kWh	kilowatt-hour
LAAFB	Los Angeles Air Force Base
LaaR	Load acting as Resource
LAX	Los Angeles International Airport
lb	pound
LBNL	Lawrence Berkeley National Laboratory
LCFS	low carbon fuel standard
MCP	market clearing price
MDL	McGuire-Dix-Lakehurst
MPG	mile(s) per gallon
MPGe	miles per gallon equivalent
MY	model year
Nissan	Nissan North America, Inc.
O&M	operations and maintenance
OBDC	on-board data collector
OB-EVI	On-Base EV Infrastructure
OCPP	Open Charge Point Protocol
OEM	original equipment manufacturer
OSD	Office of the Secretary of Defense
OT&E	operational test and evaluation
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
Phoenix	Phoenix Motorcars, LLC
PJM	PJM Interconnection LLC
PPS	Princeton Power Systems, Inc.
PTO	Permission to Operate
QSE	Qualified Service Entity
qty	quantity
R&D	Research and Development
RDT&E	Research, Development, Test and Evaluation
REEV	Range Extended Electric Vehicle
RTCC	Real Time Control Component
RTO	Regional Transmission Organization
RXSC	Acquisitions Systems Support Branch, Systems Support Division, Materials and Manufacturing Directorate

SAE	Society of Automotive Engineers
SAF/AQ	Assistant Secretary of the Air Force for Acquisitions
SAF/IE	Assistant Secretary of the Air Force for Installations, Environment and Energy
SAF/IEE	Deputy Assistant Secretary of the Air Force for Environment, Safety and Infrastructure
SC	Scheduling Coordinator
SCE	Southern California Edison
SEP2	Smart Energy Profile 2.0
SES	Simple Energy Scheduler
SMC	Space and Missile Systems Center
SOC	state-of-charge
STIG	Security Technical Implementation Guide
TARDEC	Tank and Automotive Research, Development, and Engineering Center
TCP/IP	Transmission Control Protocol/Internet Protocol
TRL	technology readiness level
TSP	Transition Support Plan
U.S.	United States
UC Berkeley	University of California, Berkeley
USAF	United States Air Force
USMC	United States Marine Corps
V	volt
V2G	vehicle-to-grid
VAC	volts alternating current
VDC	volts direct current
VIA	VIA Motors Inc.
VIM	vehicle interface module
Viridity	Viridity Energy
VLAN	virtual local area network
WDAT	Wholesale Distribution Access Tariff